# Hunting for Low Luminosity AGN Using Optical and X-ray Emission

## (SDSS & ROSAT All Sky Survey)


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There are now a million galaxies with spectra from the SDSS. The ROSAT All Sky Survey contains more than a hundred thousand sources over the whole sky. Thus, among the weak sources that dominate the samples, chance coincidences will be the rule rather than the exception. So, how do we determine which low luminosity AGN are producing detectable X-rays?

How do galaxies and their central black holes co-evolve?

How do we find out?

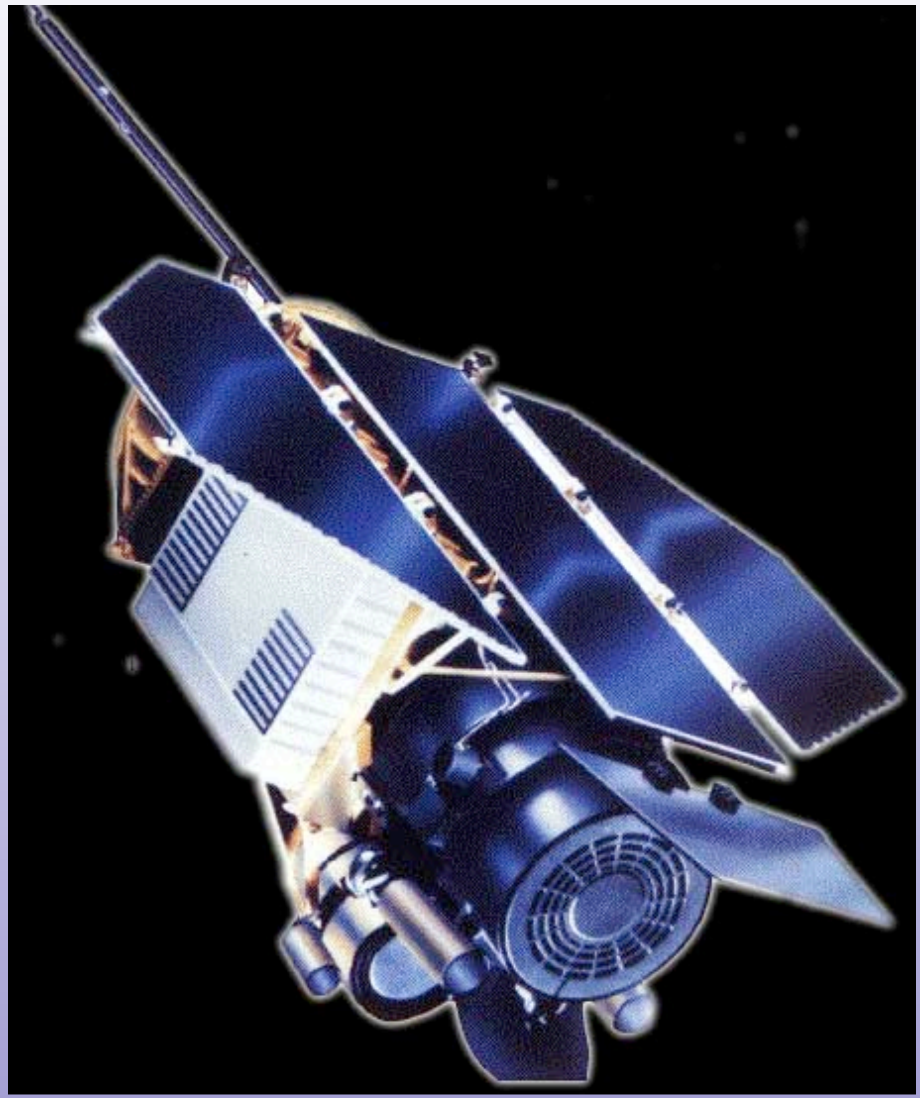
How do we prove it?

My thesis?  These questions are very big, but I can chip away at them.

# Sloan Digital Sky Survey

- Optical survey of the "local" universe
- ~1,000,000 galaxy spectra
- 11,000 degrees of the sky
- Resolution: ~1.4"
- brightness limit: $2.3 \times 10^{-14}$ erg/s/cm$^2$

- Soft X-ray survey of the "local" universe
- ~100,000 sources
- "All sky"
- Resolution: ~30"
- brightness limit: ~$10^{-13}$ erg/s/cm$^2$



# ROSAT All Sky Survey

Note that the brightness limit is close to that of the SDSS!
But, obscuration is very important!

# Which of the following types of objects have members that were detected by both the SDSS and RASS?

A) Ordinary main sequence stars

B) Galaxies that do not host powerful AGN

C) Isolated (non-pulsar) Neutron stars

D) All of the above

E) None of the above

# Sources in both surveys

Quasars (point source in both), Clusters (smeary source in both), cataclysmic variables (stars with black hole/neutron star companions), Bright stars (the detector isn't perfect), isolated neutron stars (all alone in the night), and even some galaxies (but it's not the galaxy itself that's being detected).
--But RASS isn't perfect: the position of the sources have large errors.

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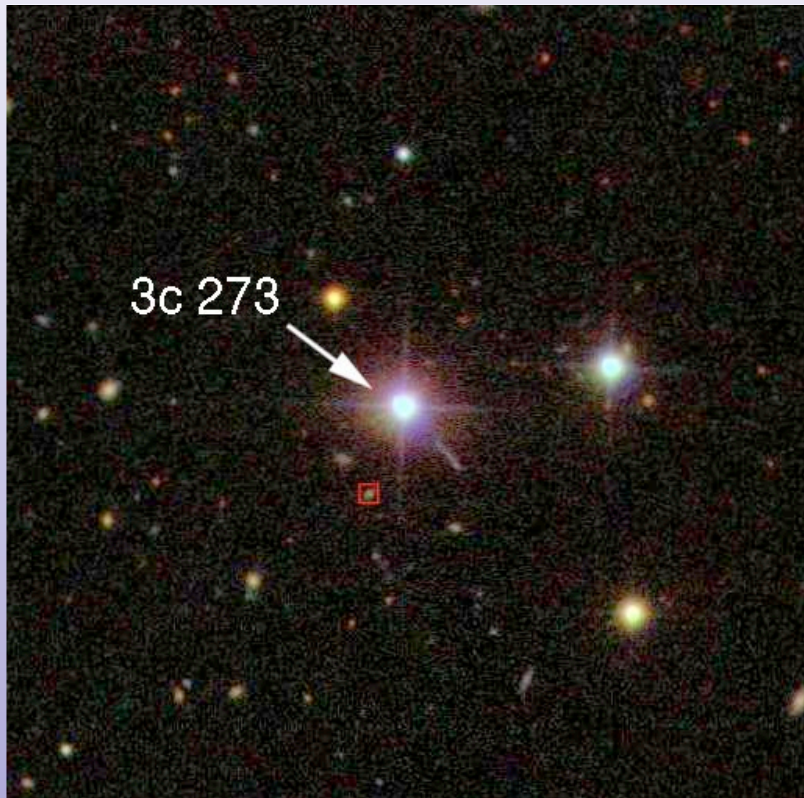


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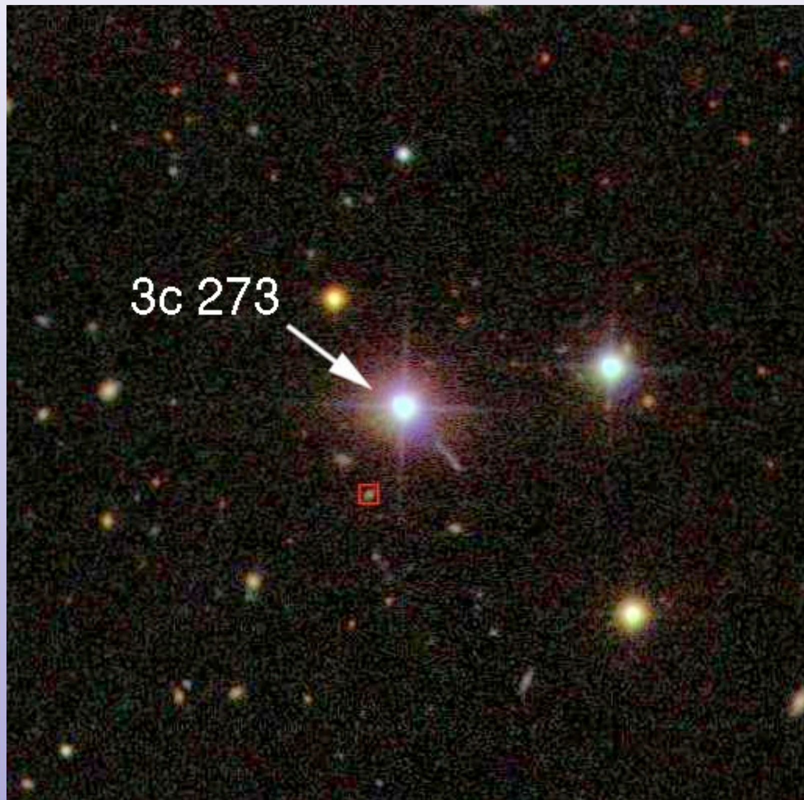


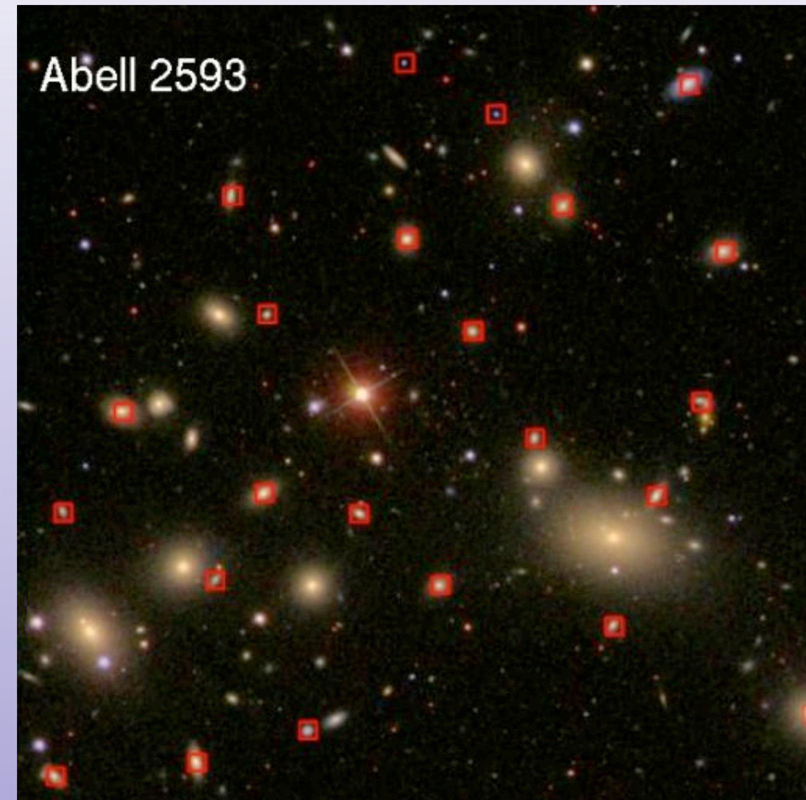


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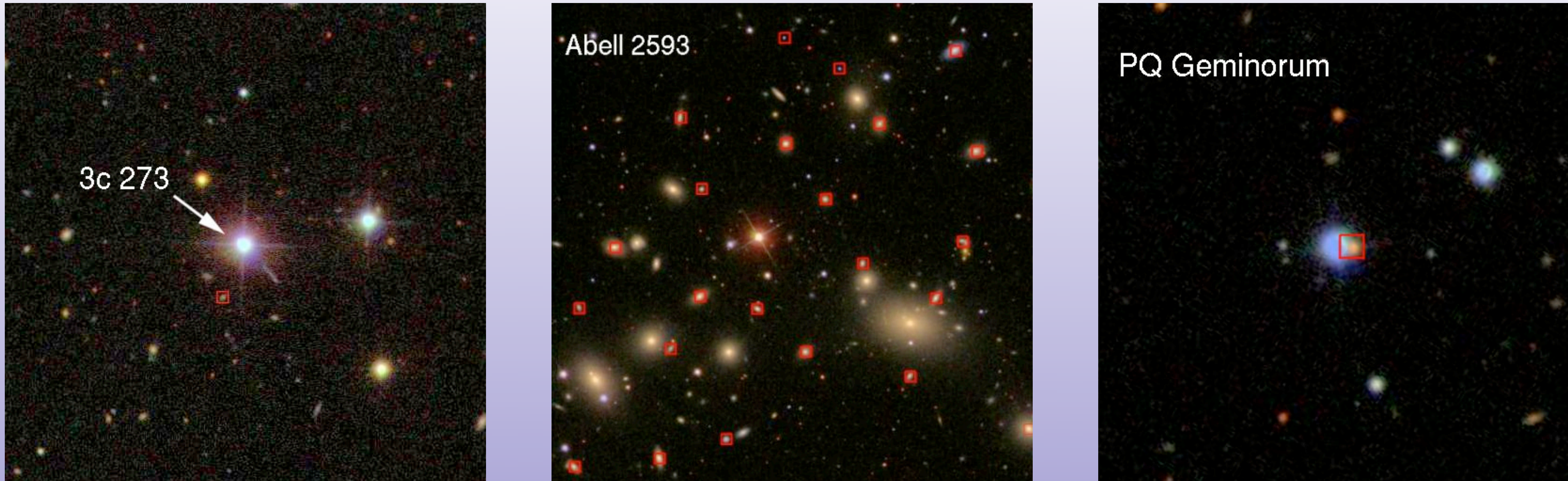


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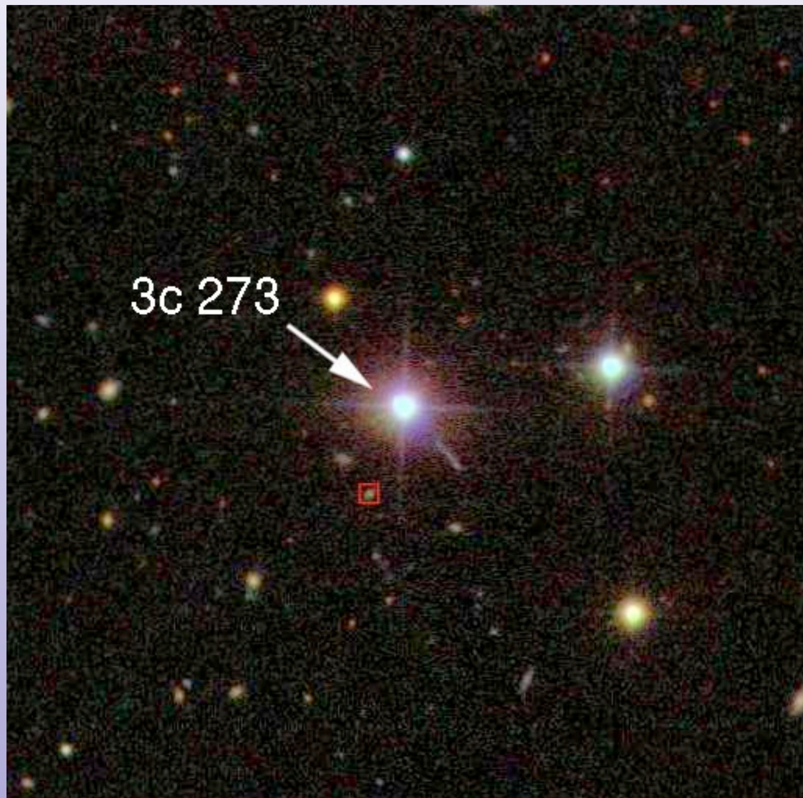


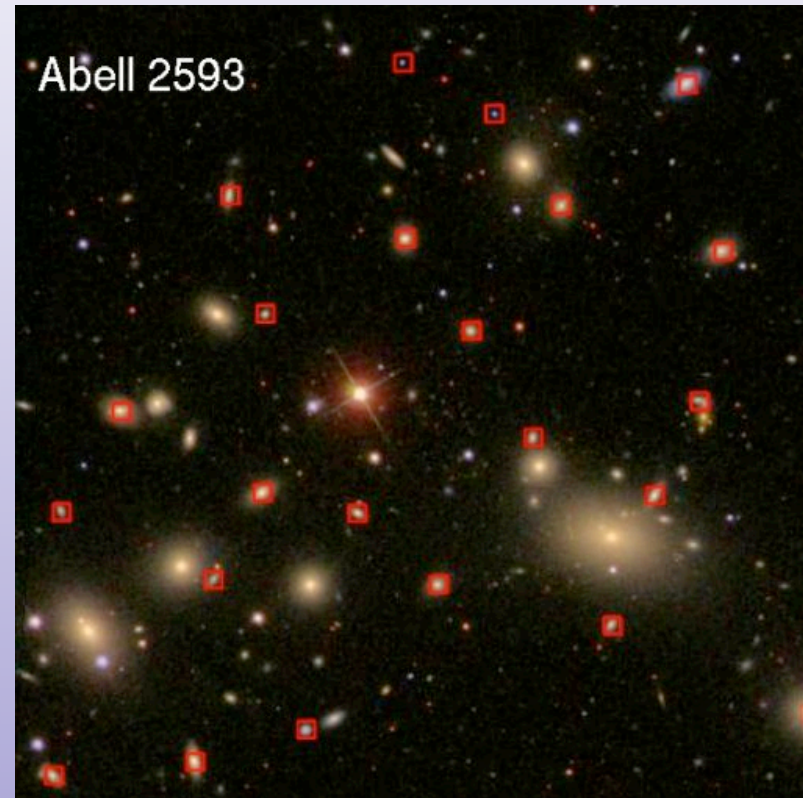


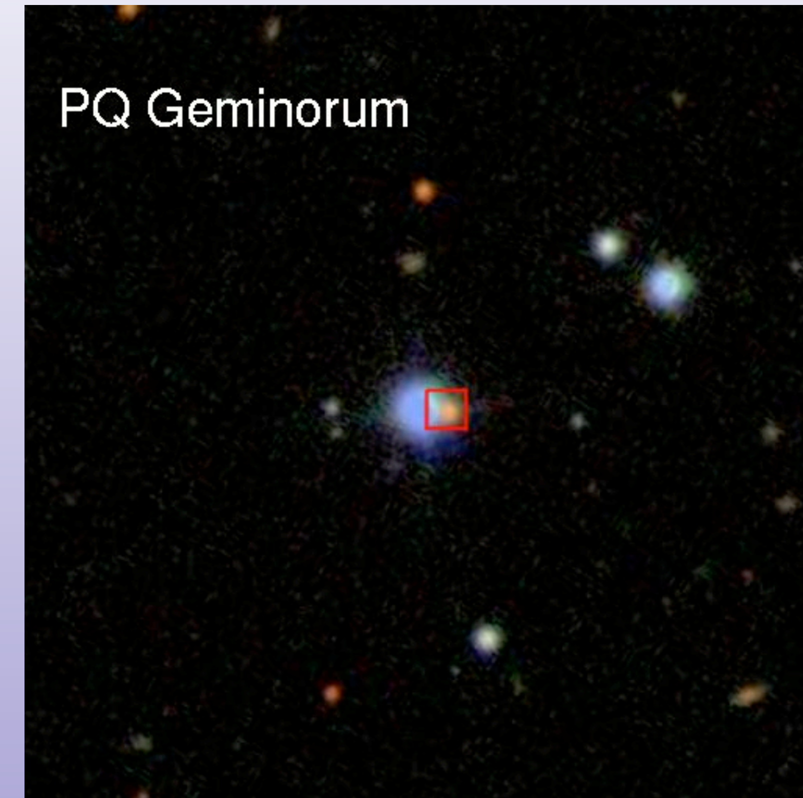


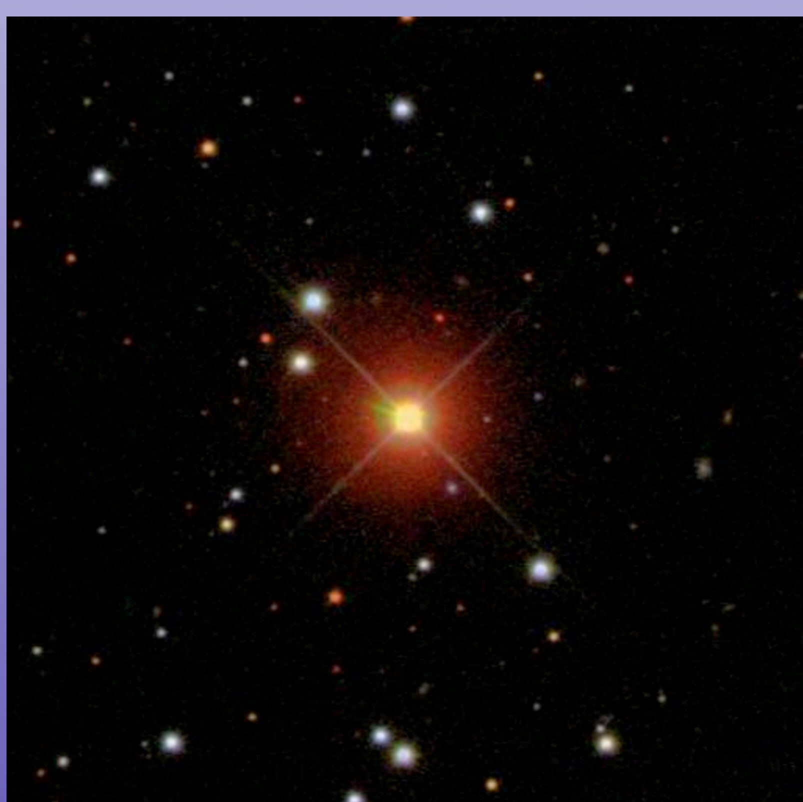

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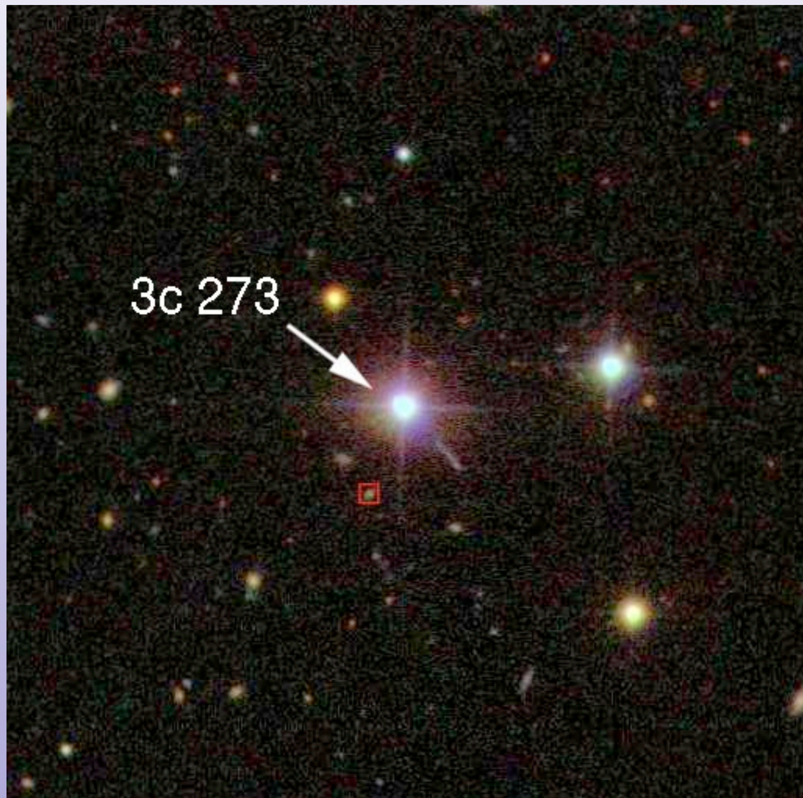


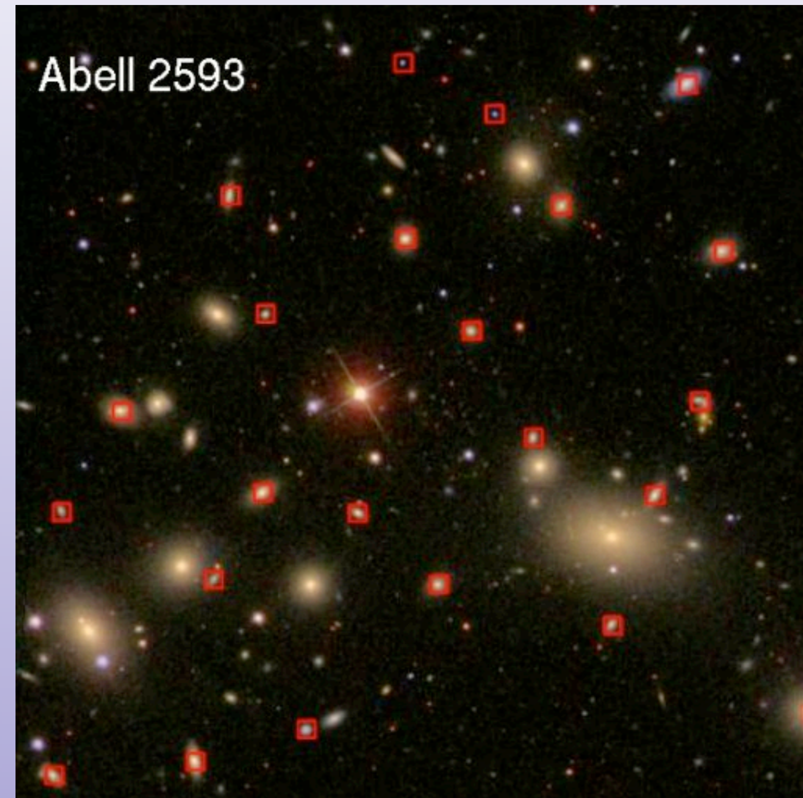


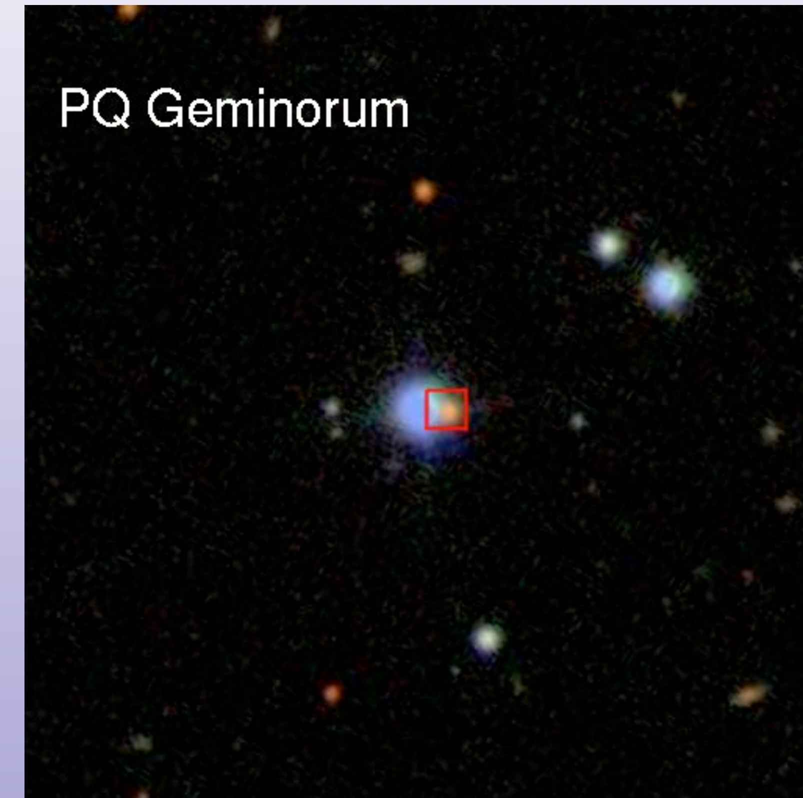


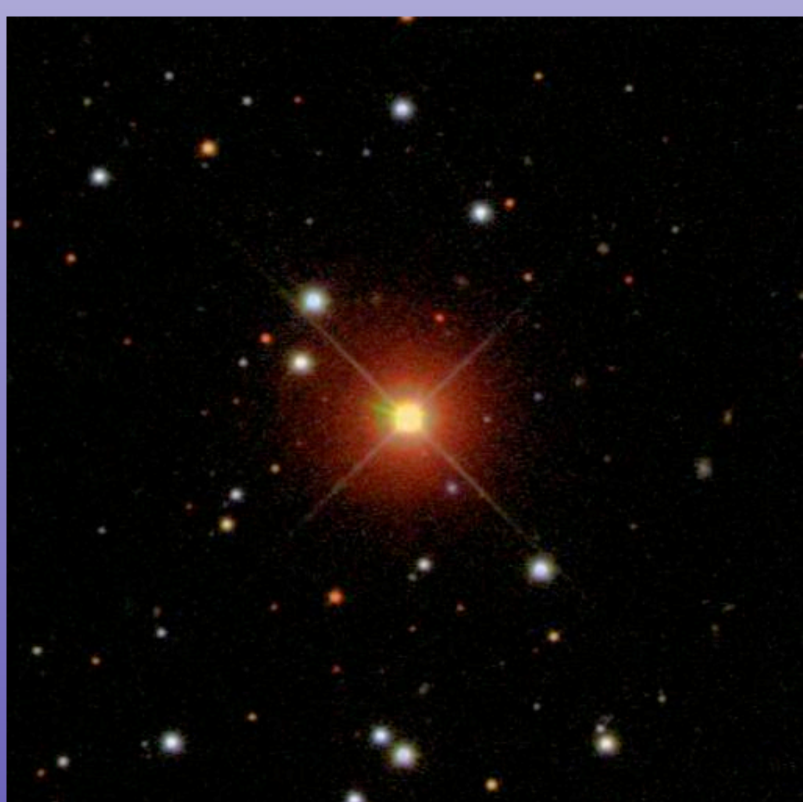

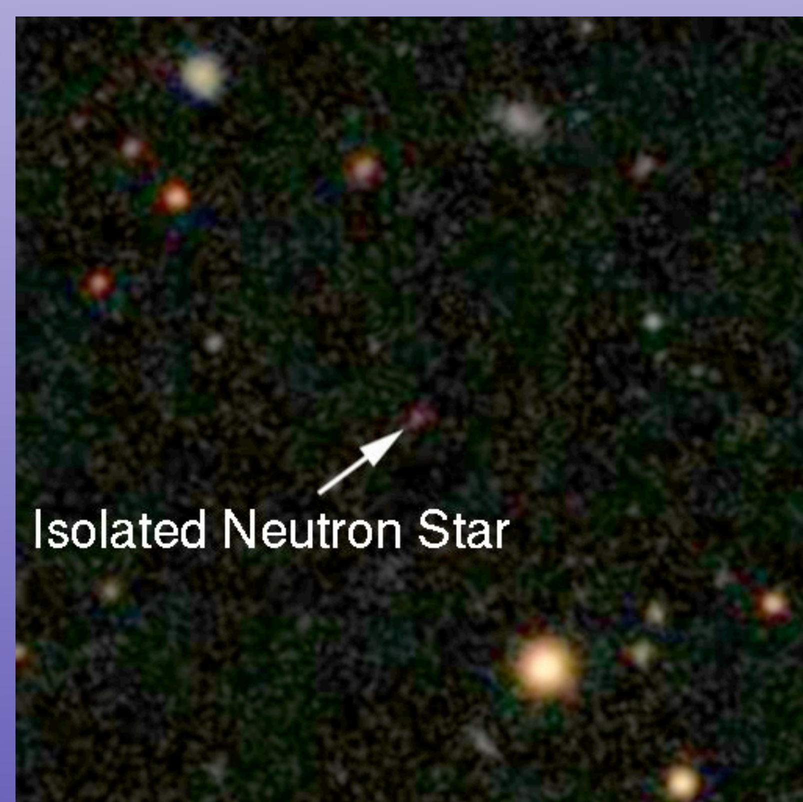


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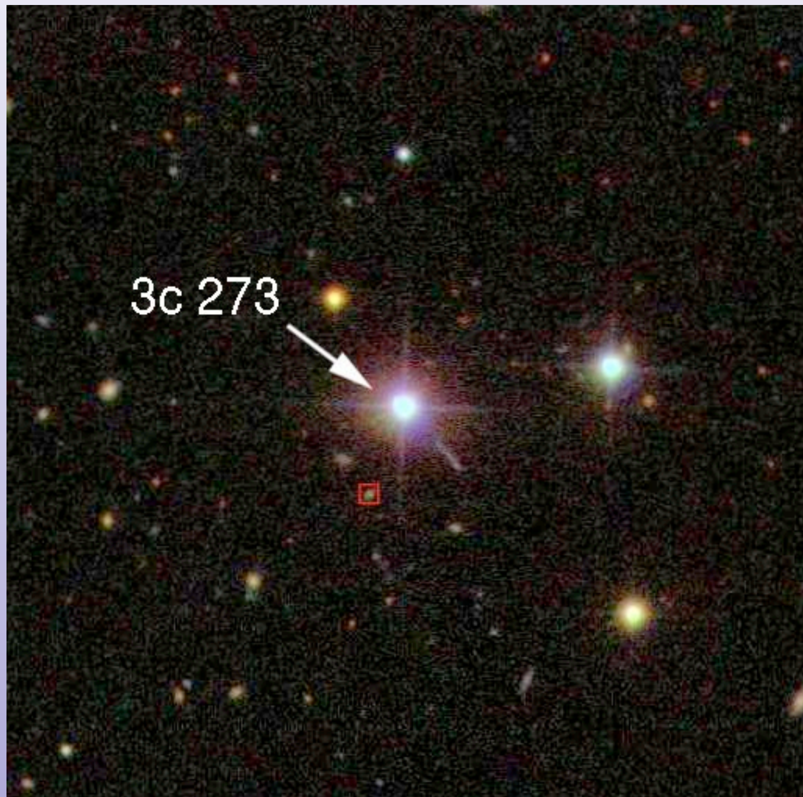


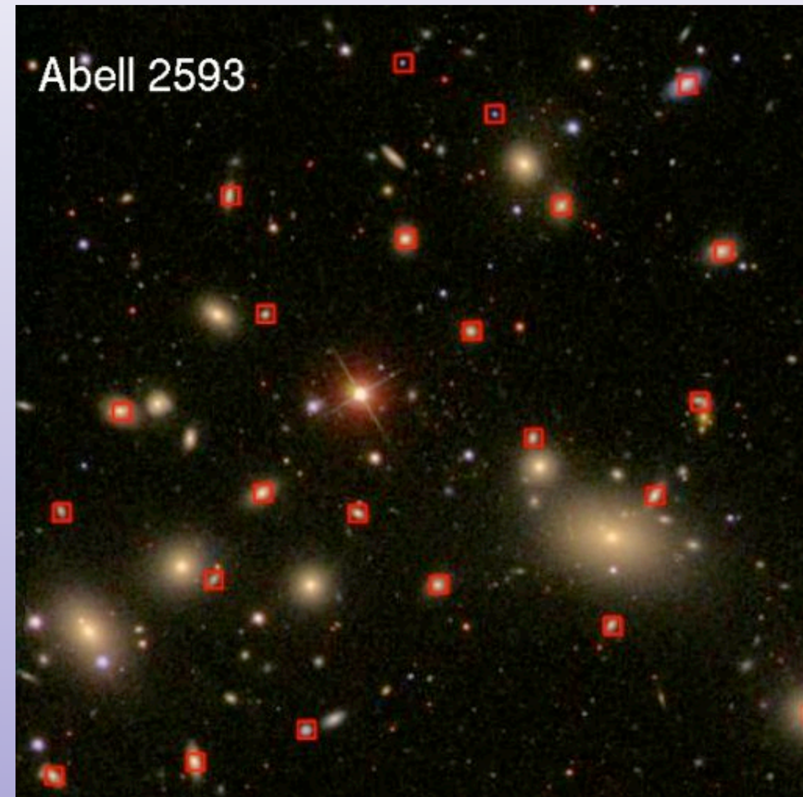


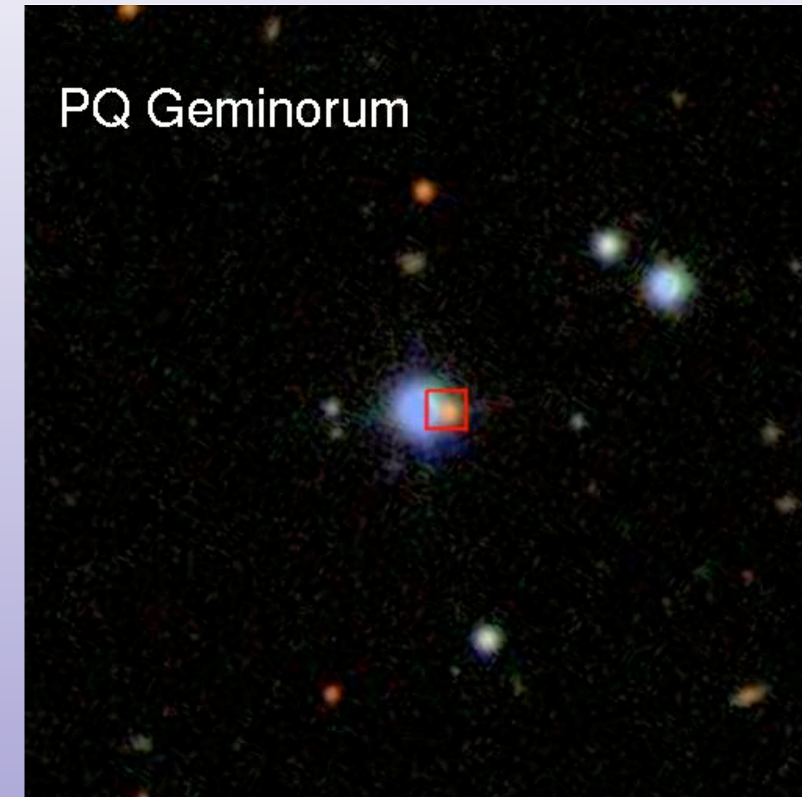


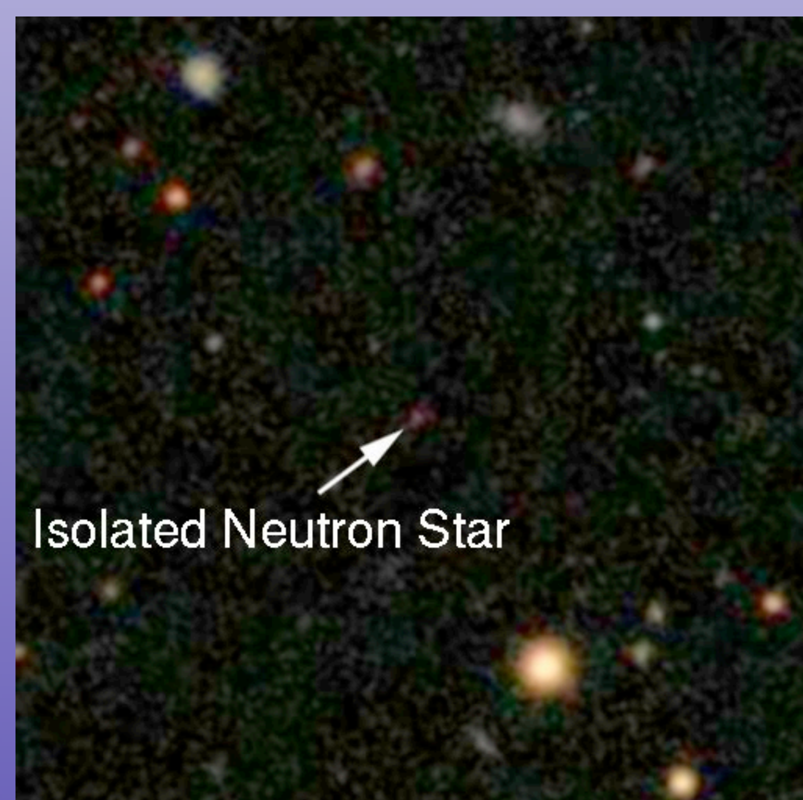


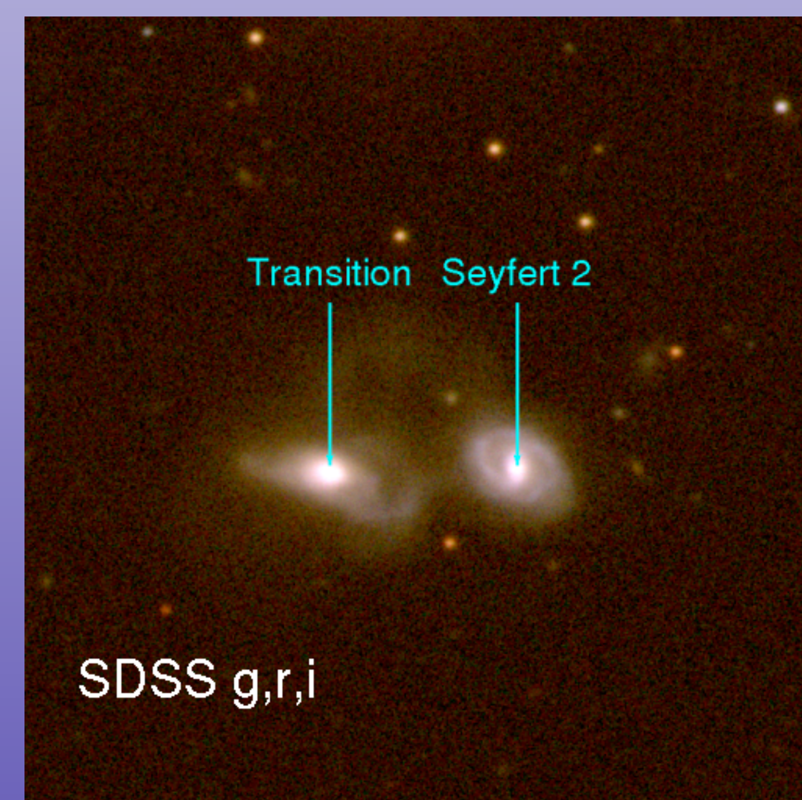


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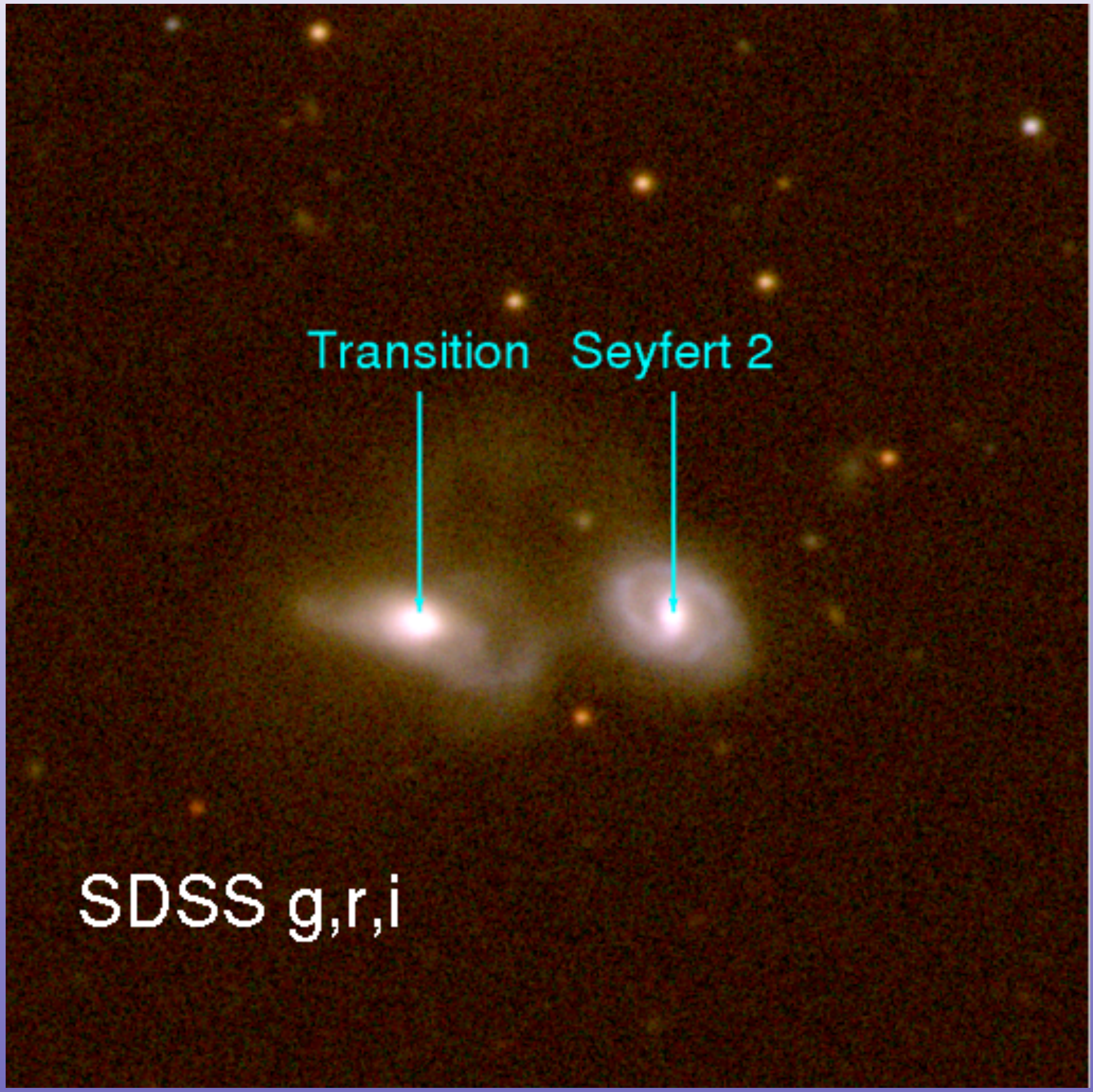


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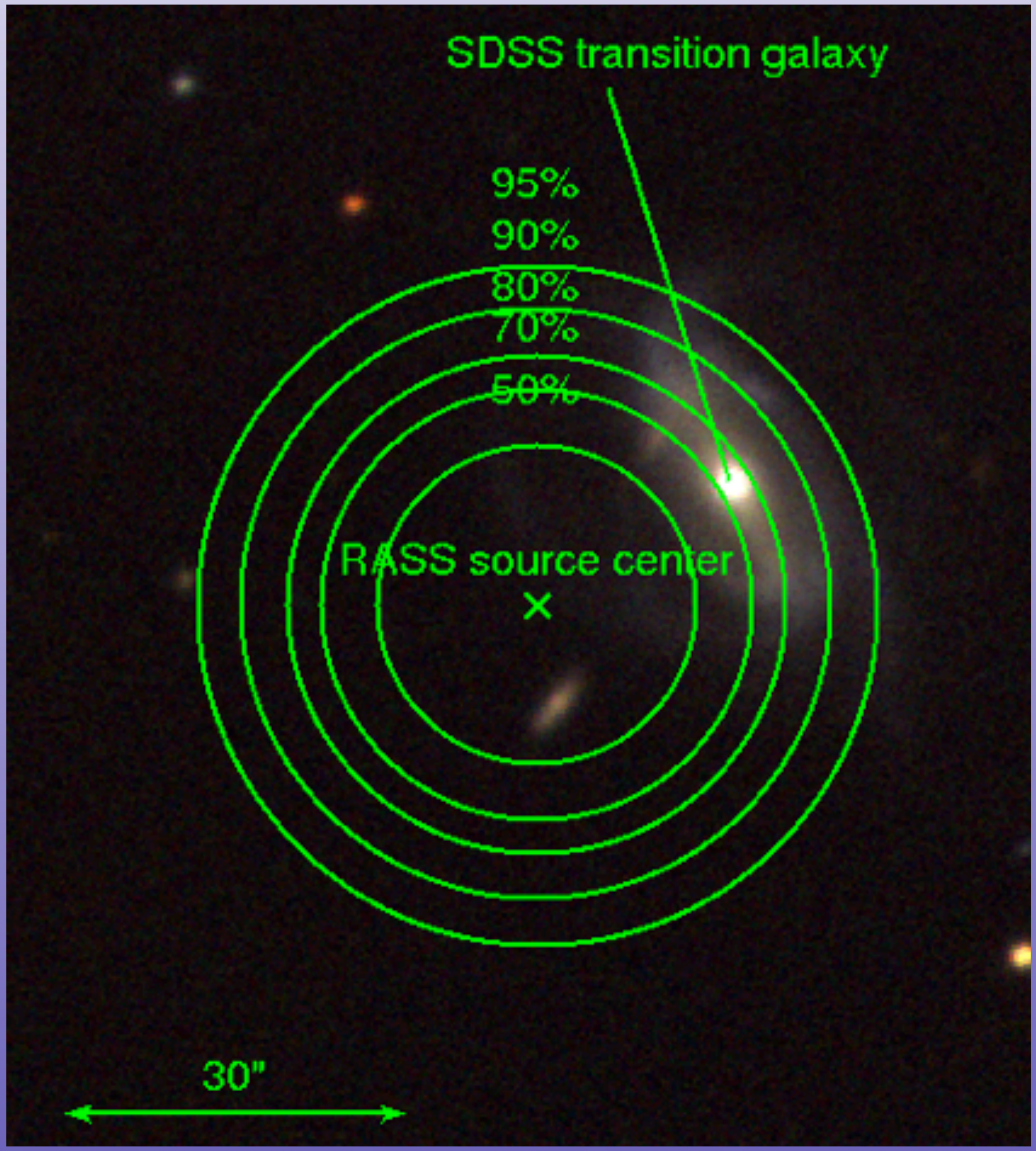
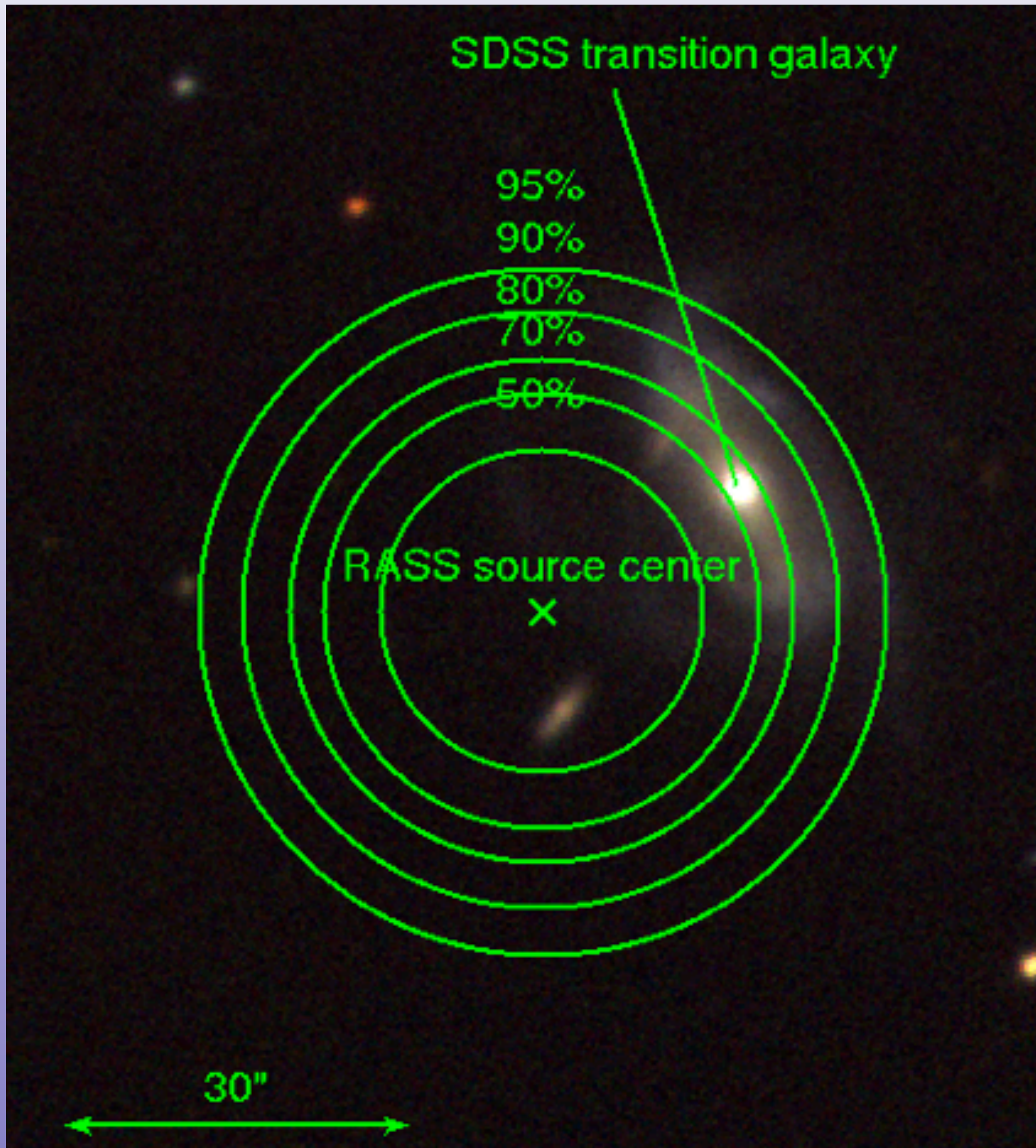
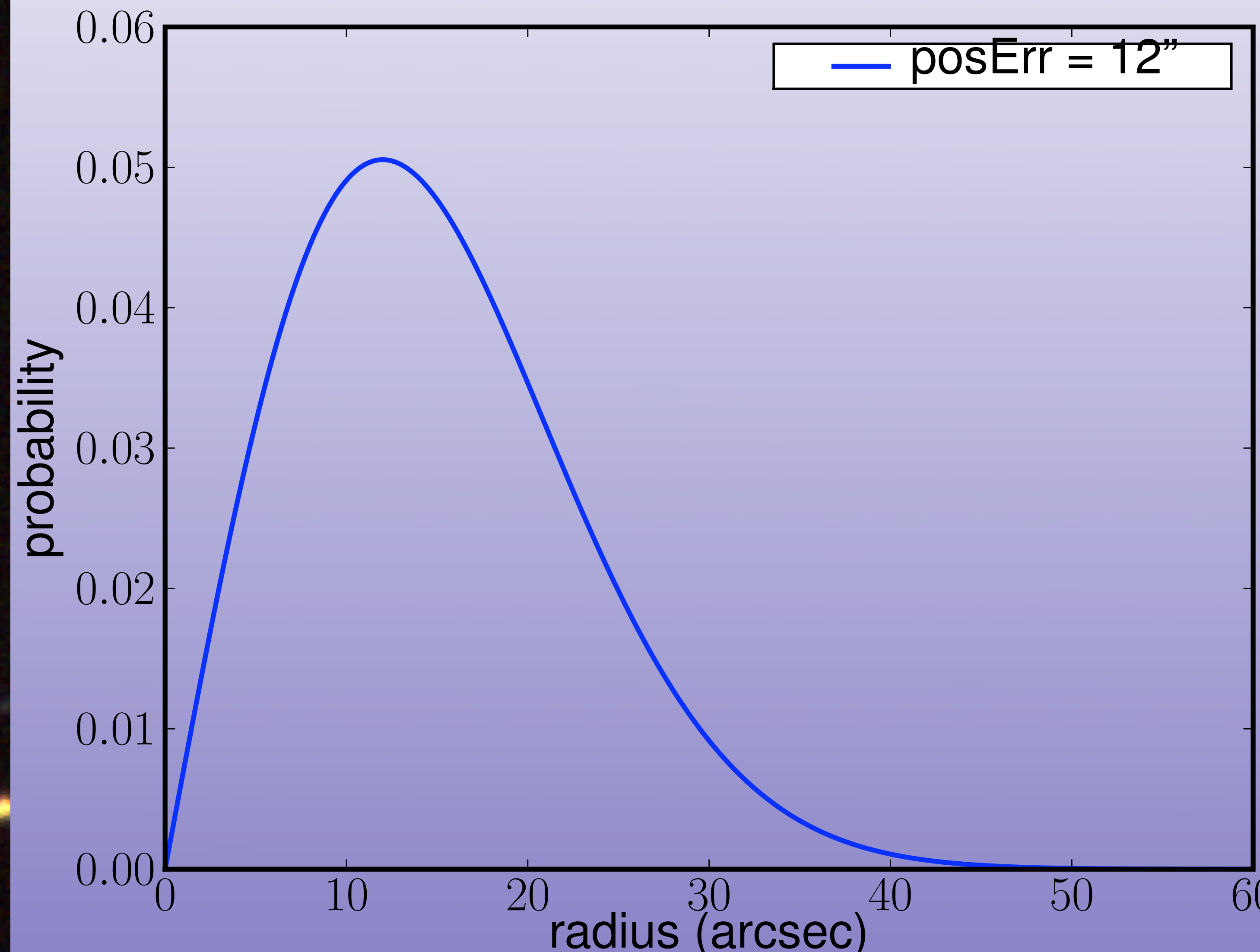
# What is the probability distribution function, P(r), resulting from by this error distribution?



# Identifying Positive Galaxy/X-ray Matches

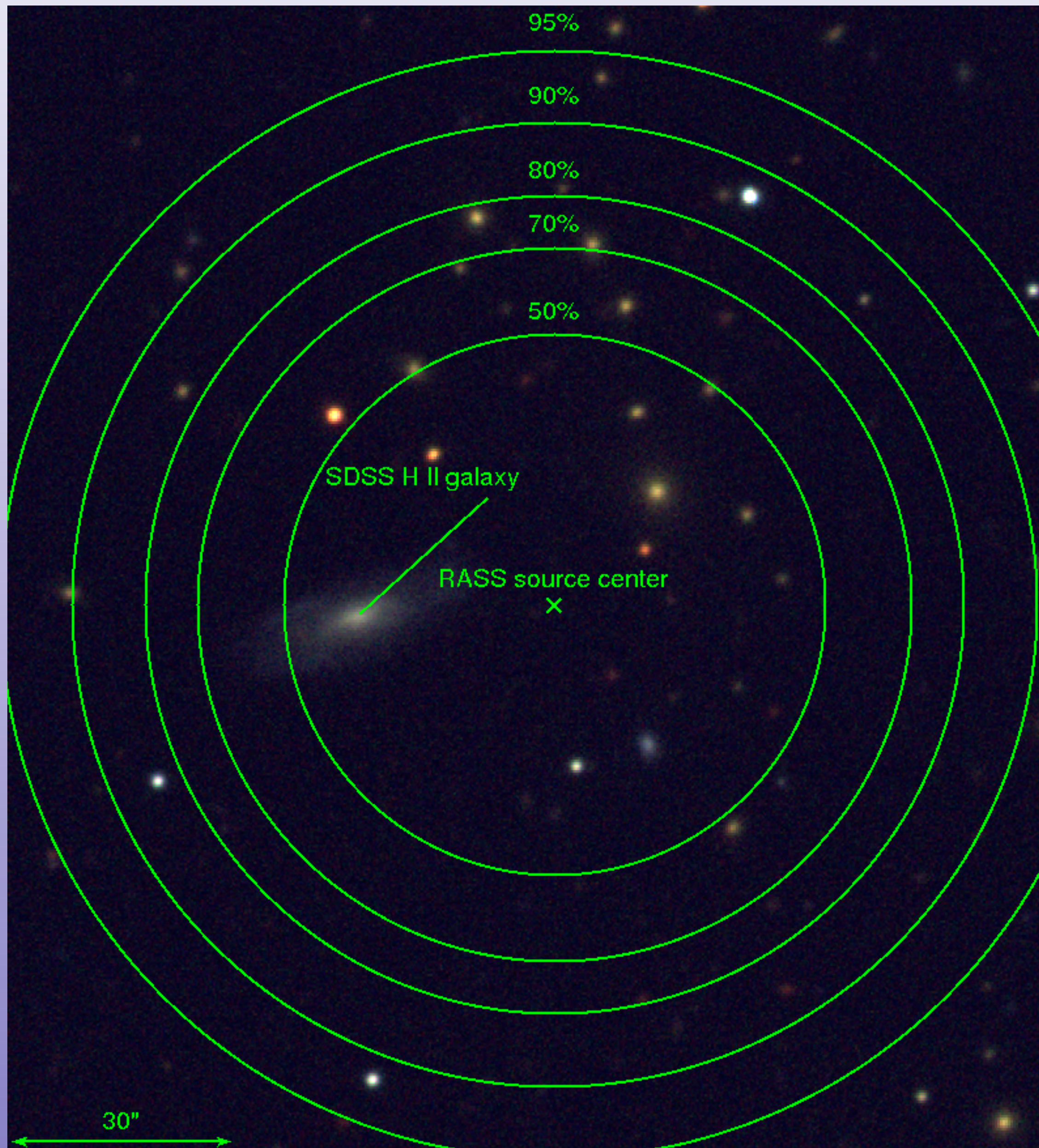


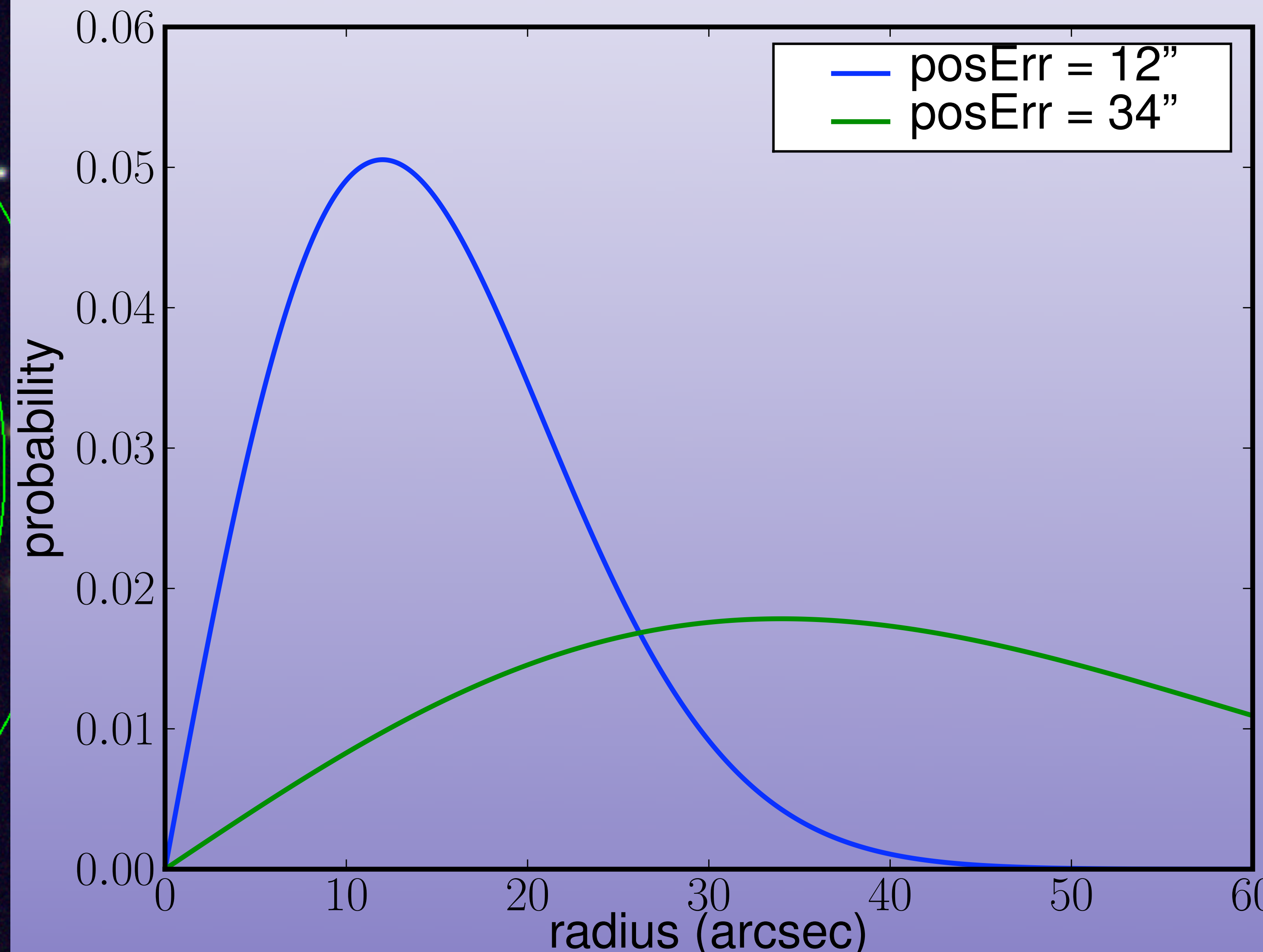




Parejko et al. (2008)

Here is an example of an actively line-emitting galaxy with the RASS positional error circles displayed. The RASS positional error can be used to predict the probability distribution for the location of the X-ray emitting source.

# Identifying Positive Galaxy/X-ray Matches

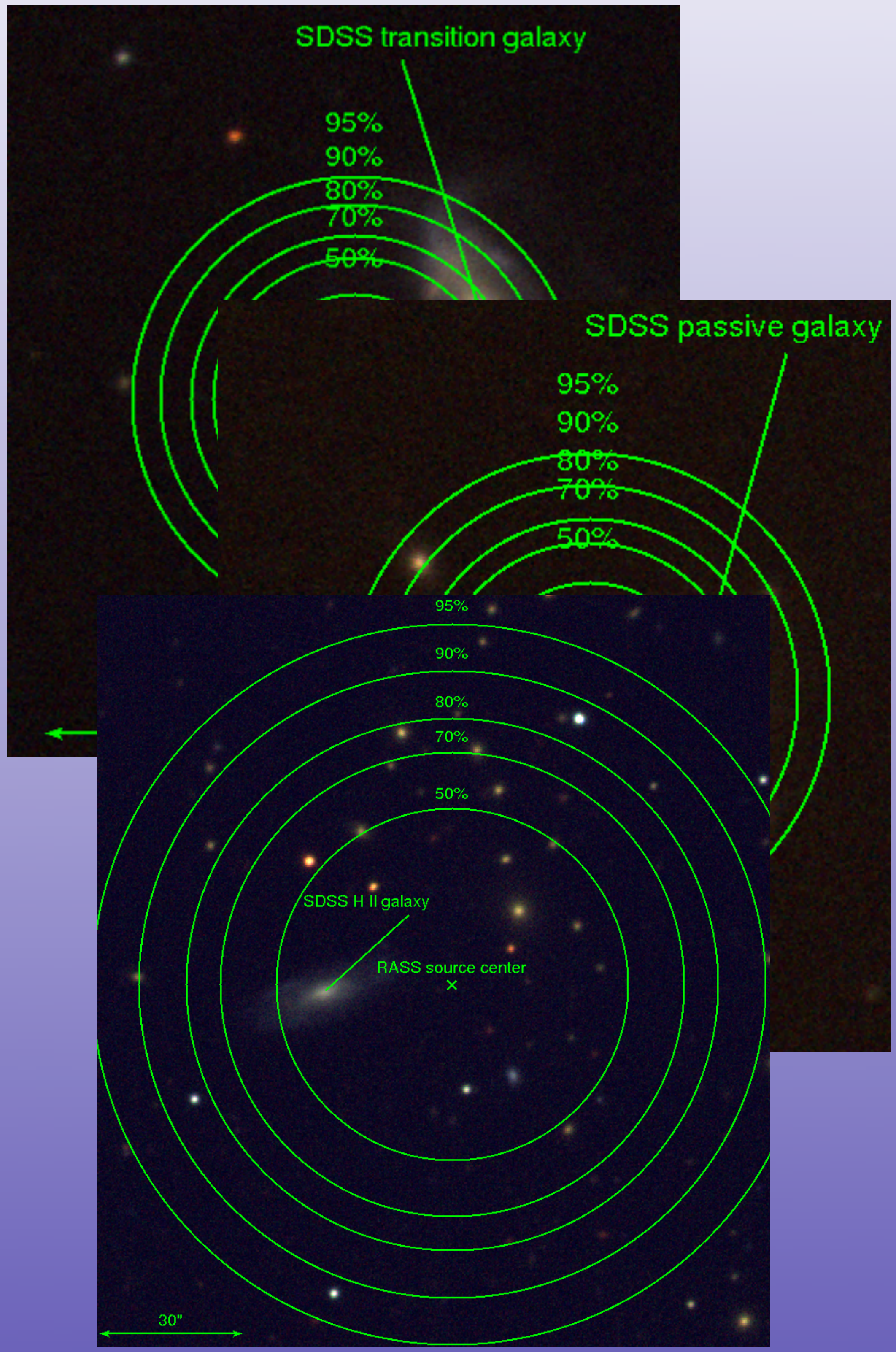


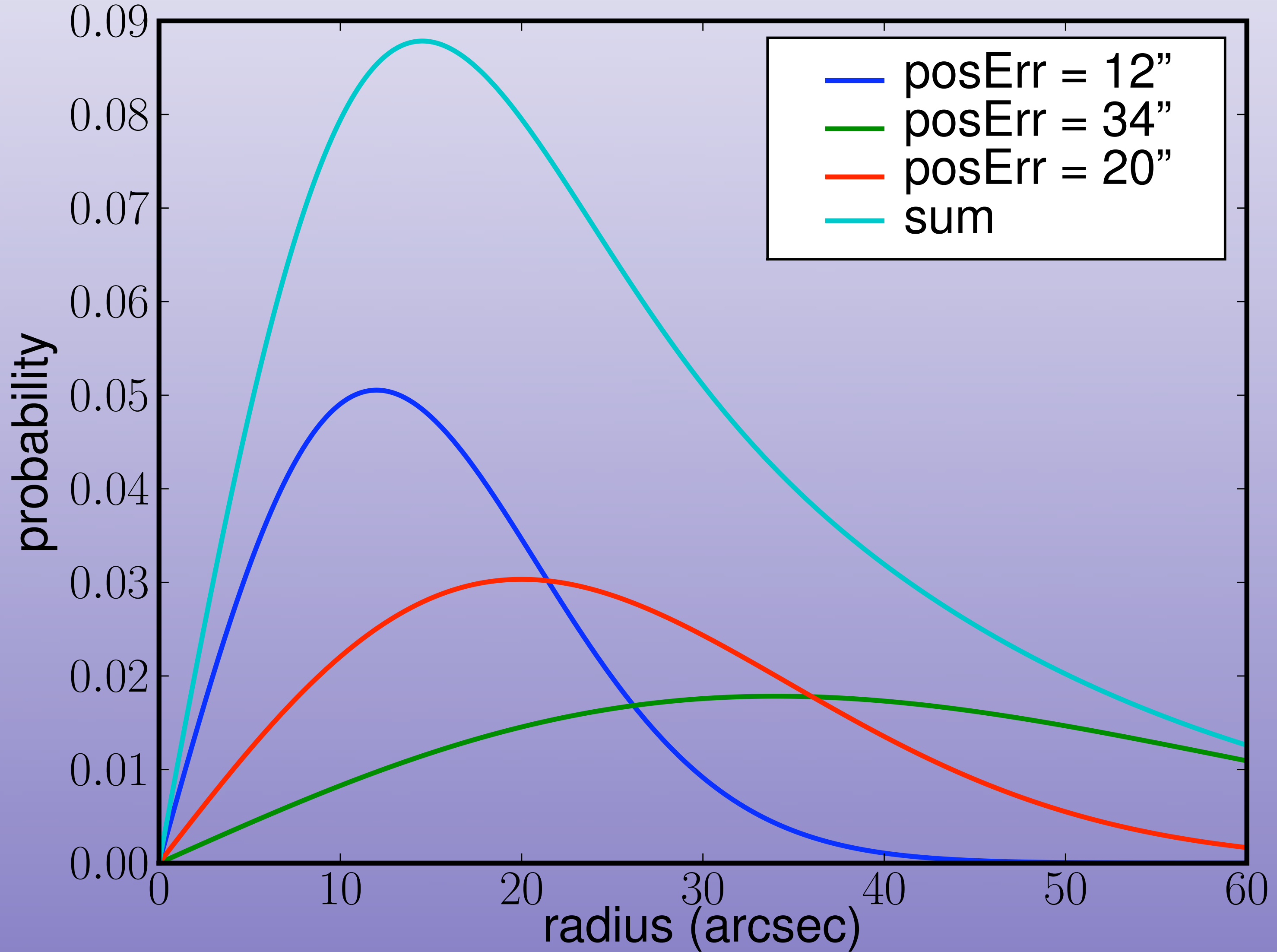

Parejko et al. (2008)

Here's a star forming galaxy. Different RASS sources have different positional errors, and thus different PDF. The large positional errors of the RASS source encompass many, many SDSS optical sources. And weak RASS sources have larger positional errors!

# Identifying Positive Galaxy/X-ray Matches




## Combining multiple "matches"

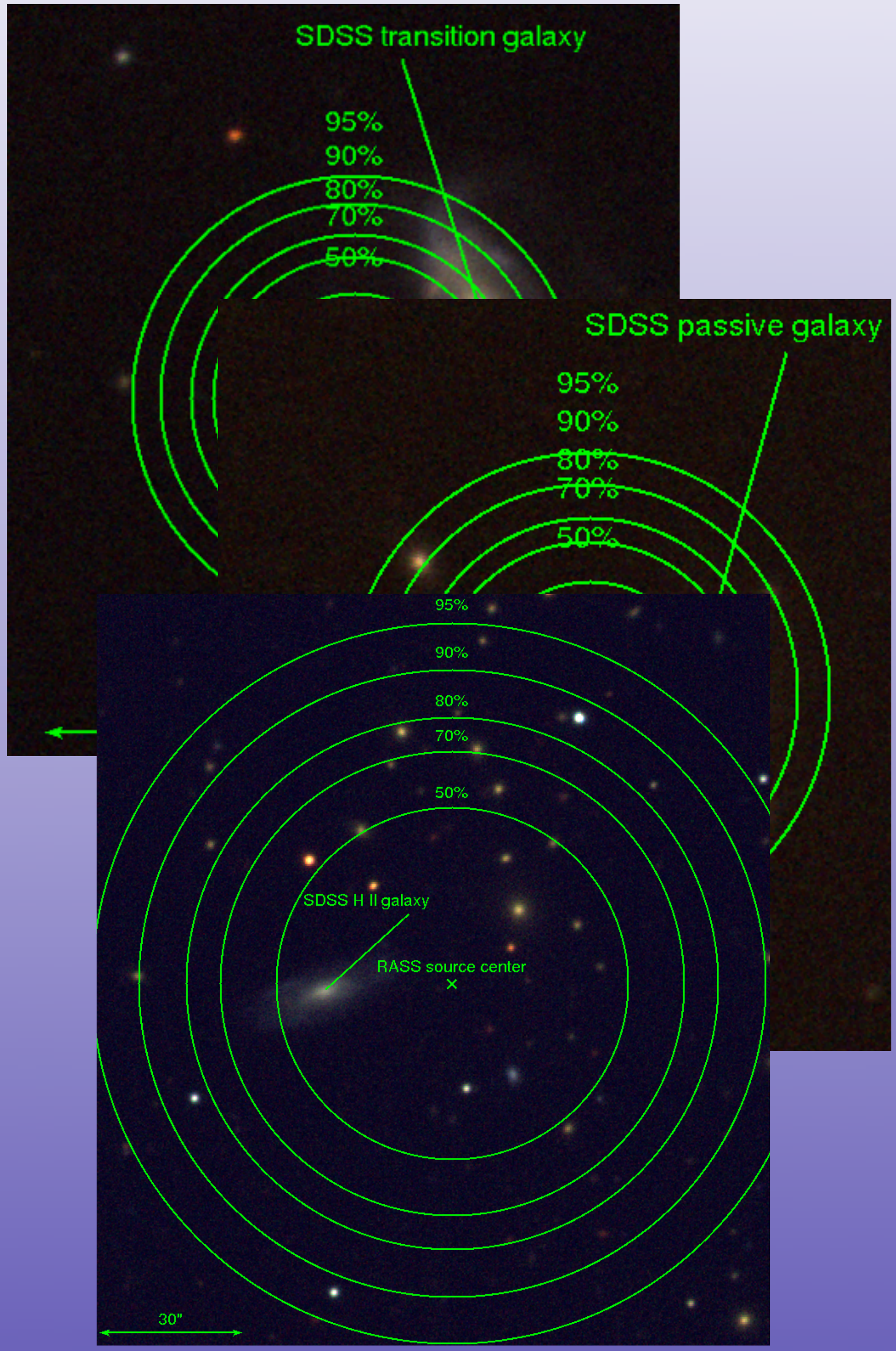



Parejko et al. (2008)

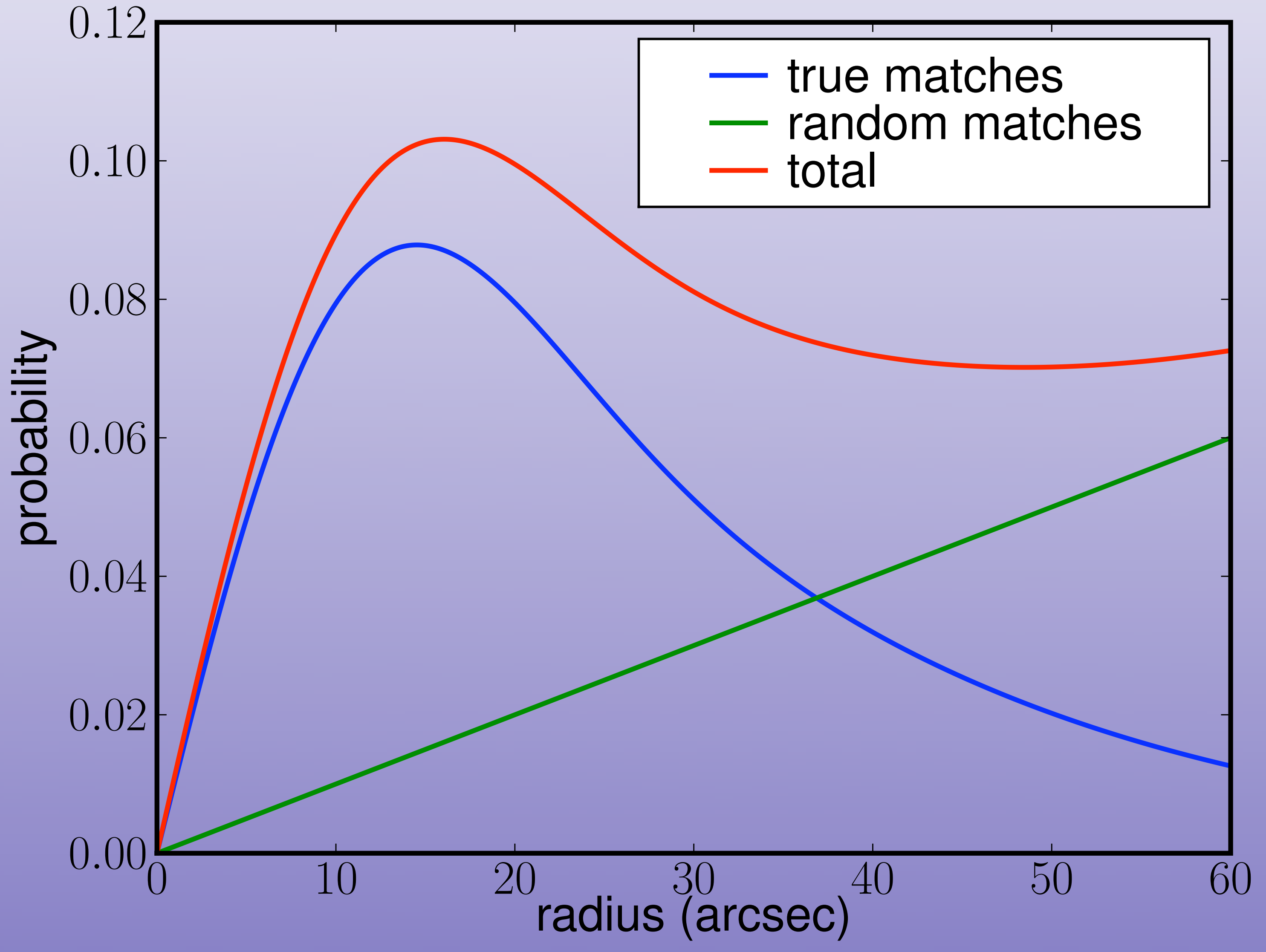
The probability distribution for all RASS vs. SDSS "matches" is the sum of the PDFs from each individual measurement... plus one more thing. Since there are so many SDSS galaxies, there will be many random associations between the two surveys.

Which probability distribution function would be produced if all of the matches between two catalogs are just coincidental (a purely "random" match)?

# Identifying Positive Galaxy/X-ray Matches



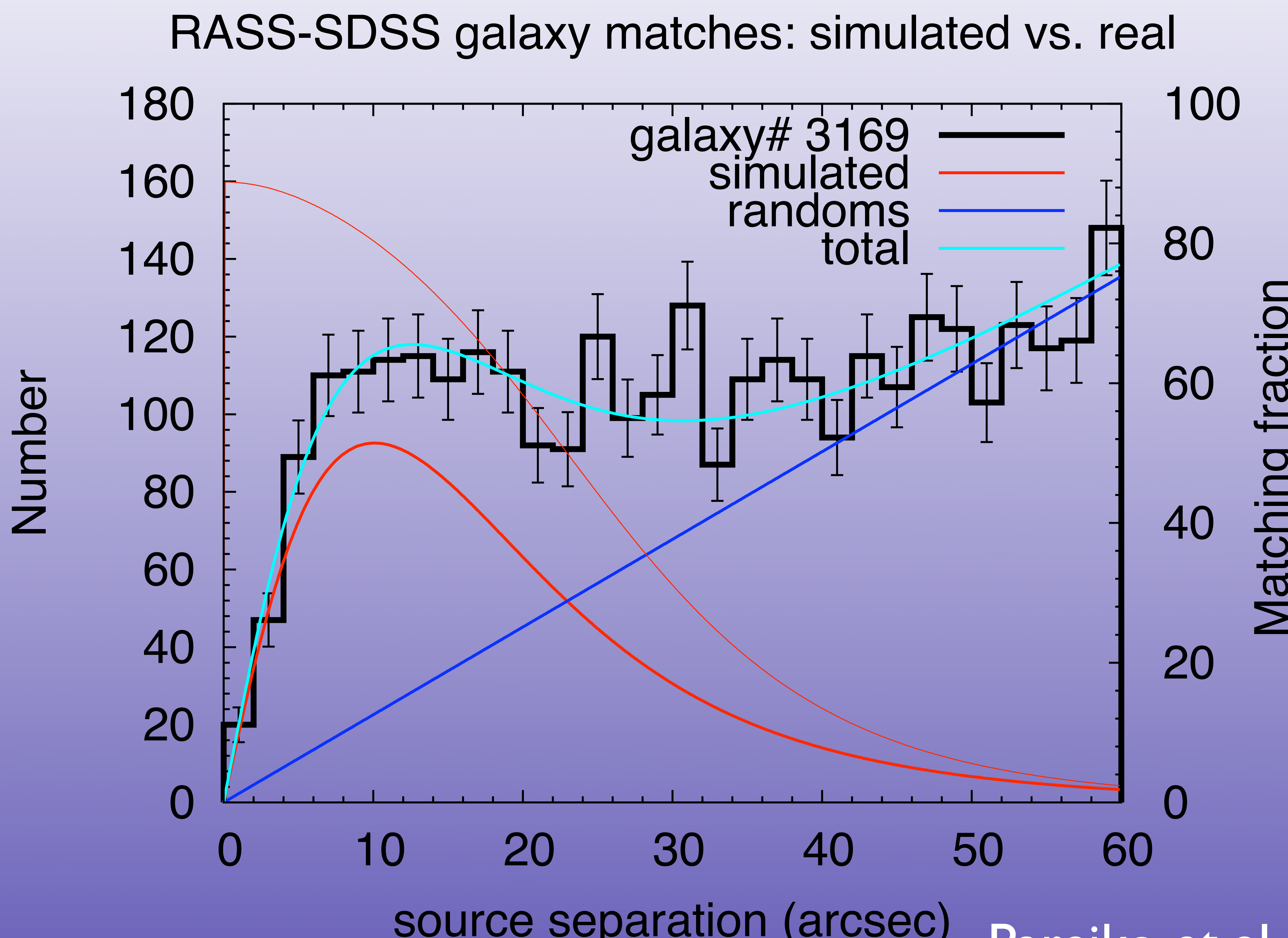

## Adding in the random associations




Parejko et al. (2008)

So we need to incorporate a random component, which increases linearly in radius (goes as the annuli: r*dr). The total "observed" distribution is thus the sum of the true match PDF plus the random match PDF (which depends on the SDSS source density). So, how well does this work in practice?

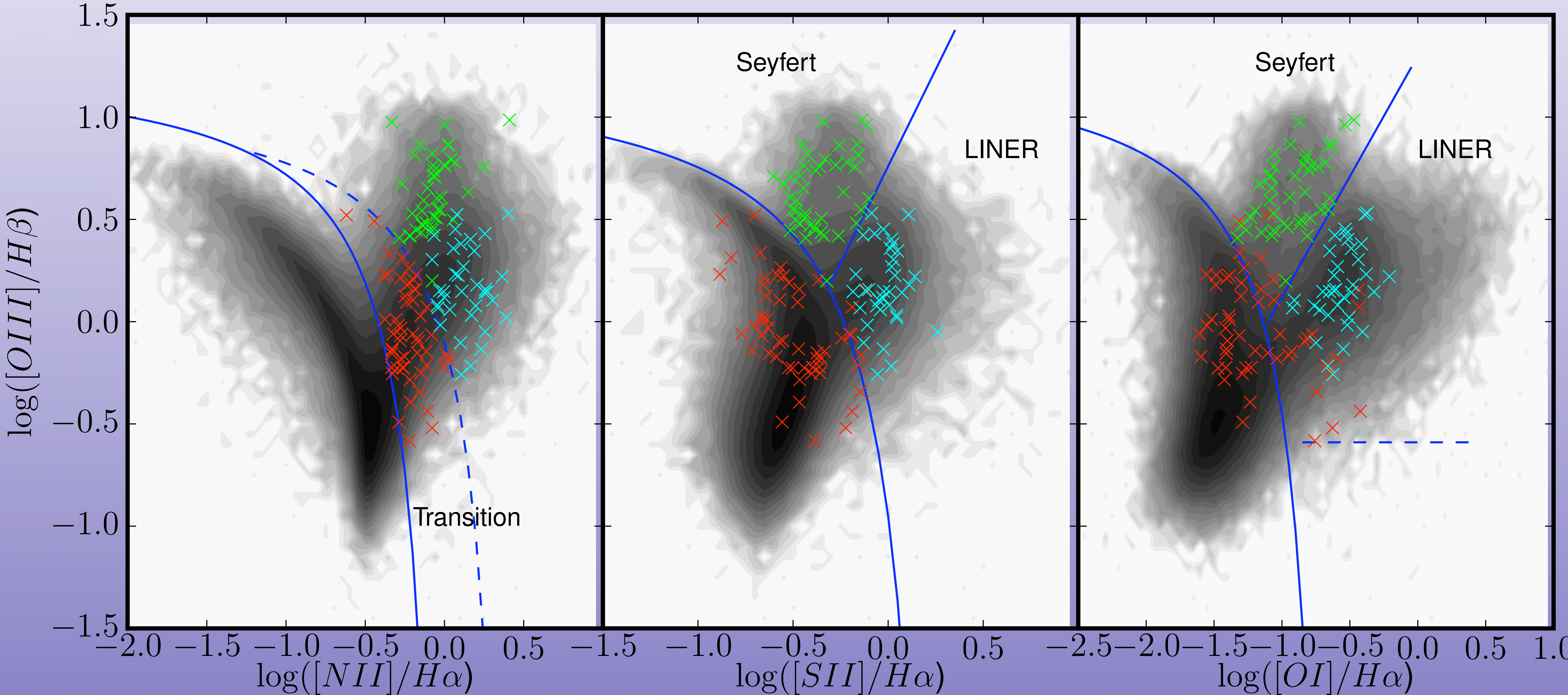
# Identifying Real Galaxy/X-ray Matches (DR4)



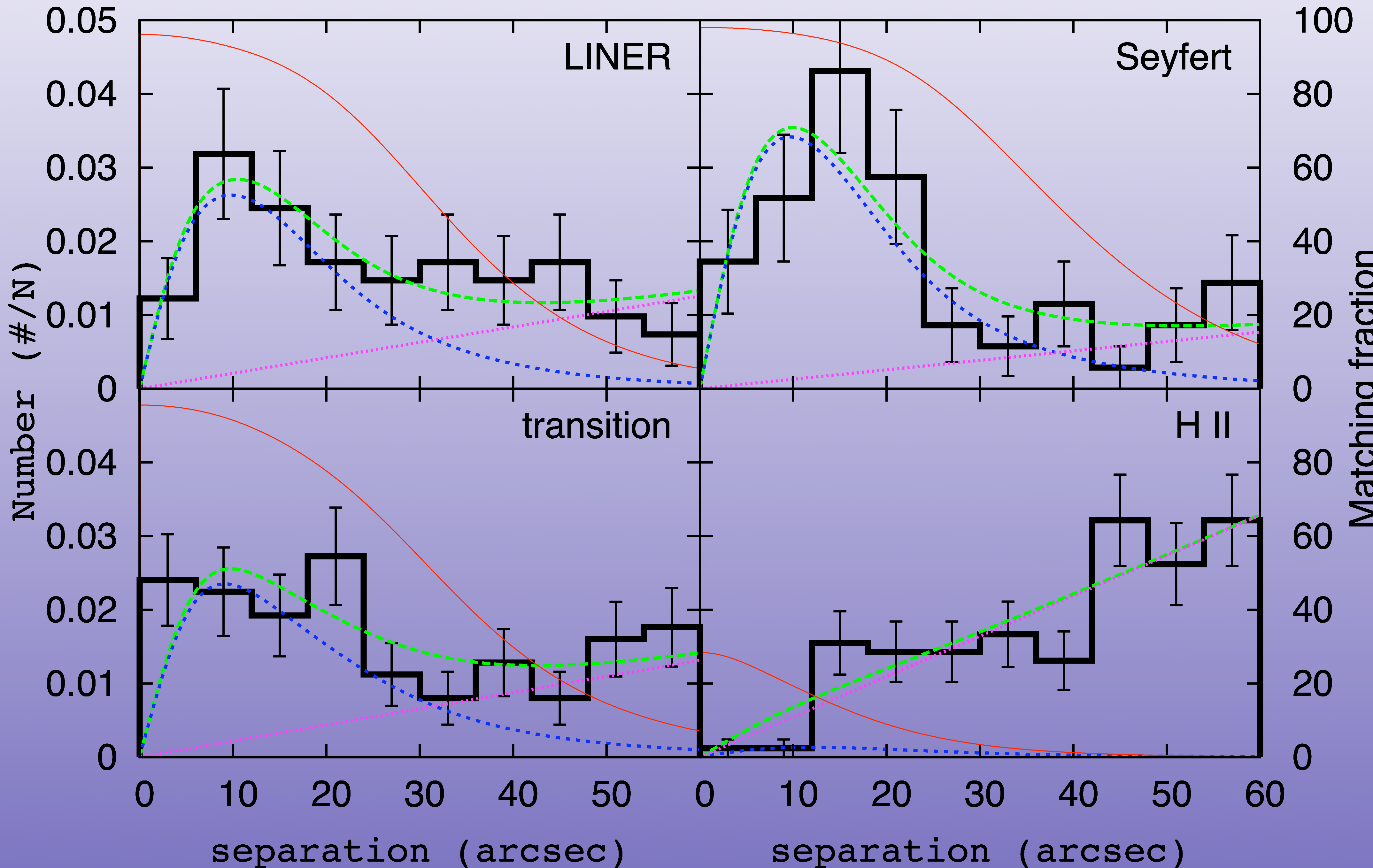

Parejko et al. (2008)

The black histogram is RASS sources matched to SDSS galaxies from DR4, the red curve is the distribution computed from the positional errors of the RASS measurements, blue is the random component and the cyan curve is the total which is an excellent match to the observations. We can use the ratio of real/total (red/cyan) to estimate the fraction of real matches at given radii in the observations. But it isn't very useful yet: lots of random associations.

# BPT classification from DR4

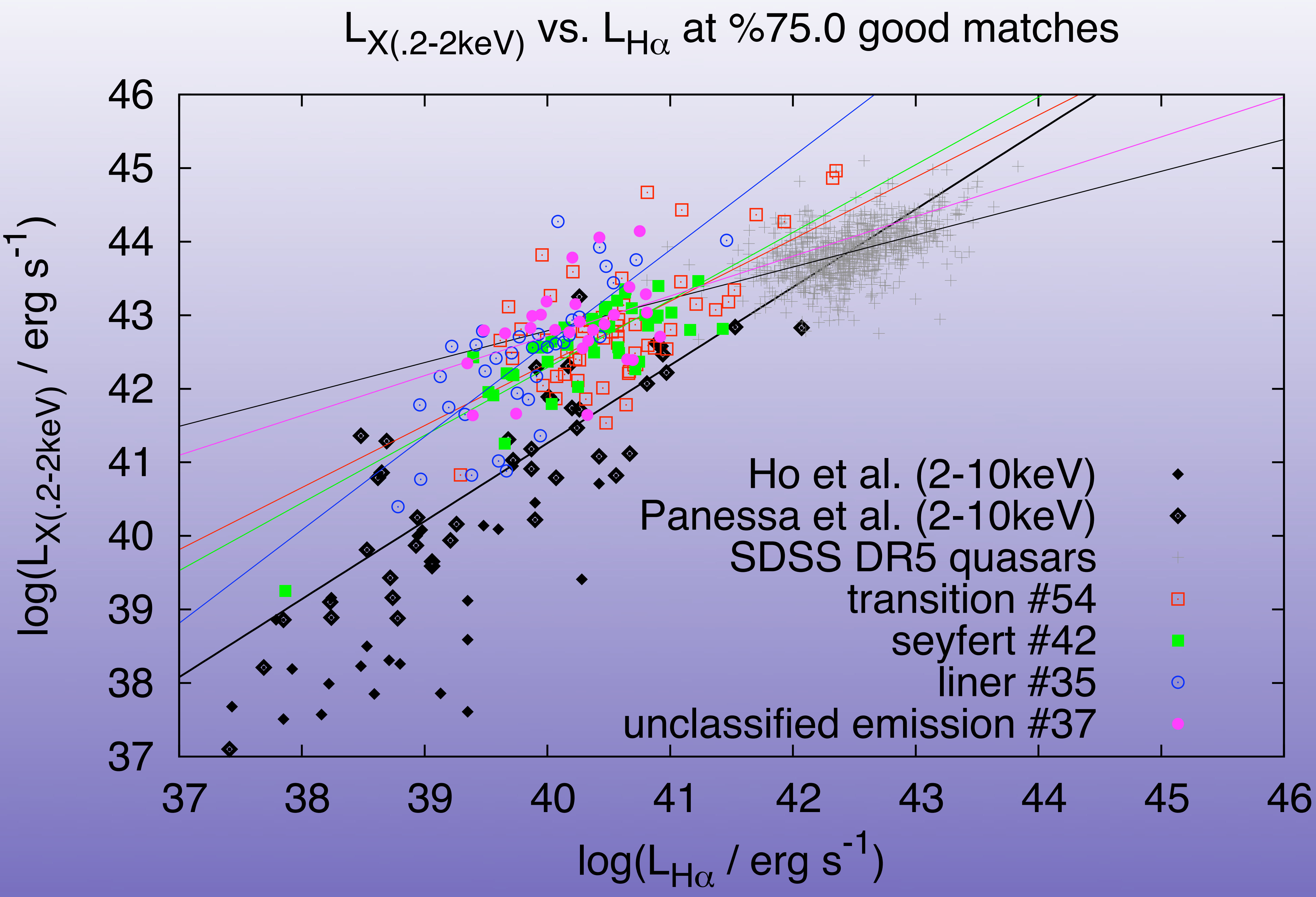


# Emission-line galaxies, by spectral class (DR4)




Parejko et al. (2008)

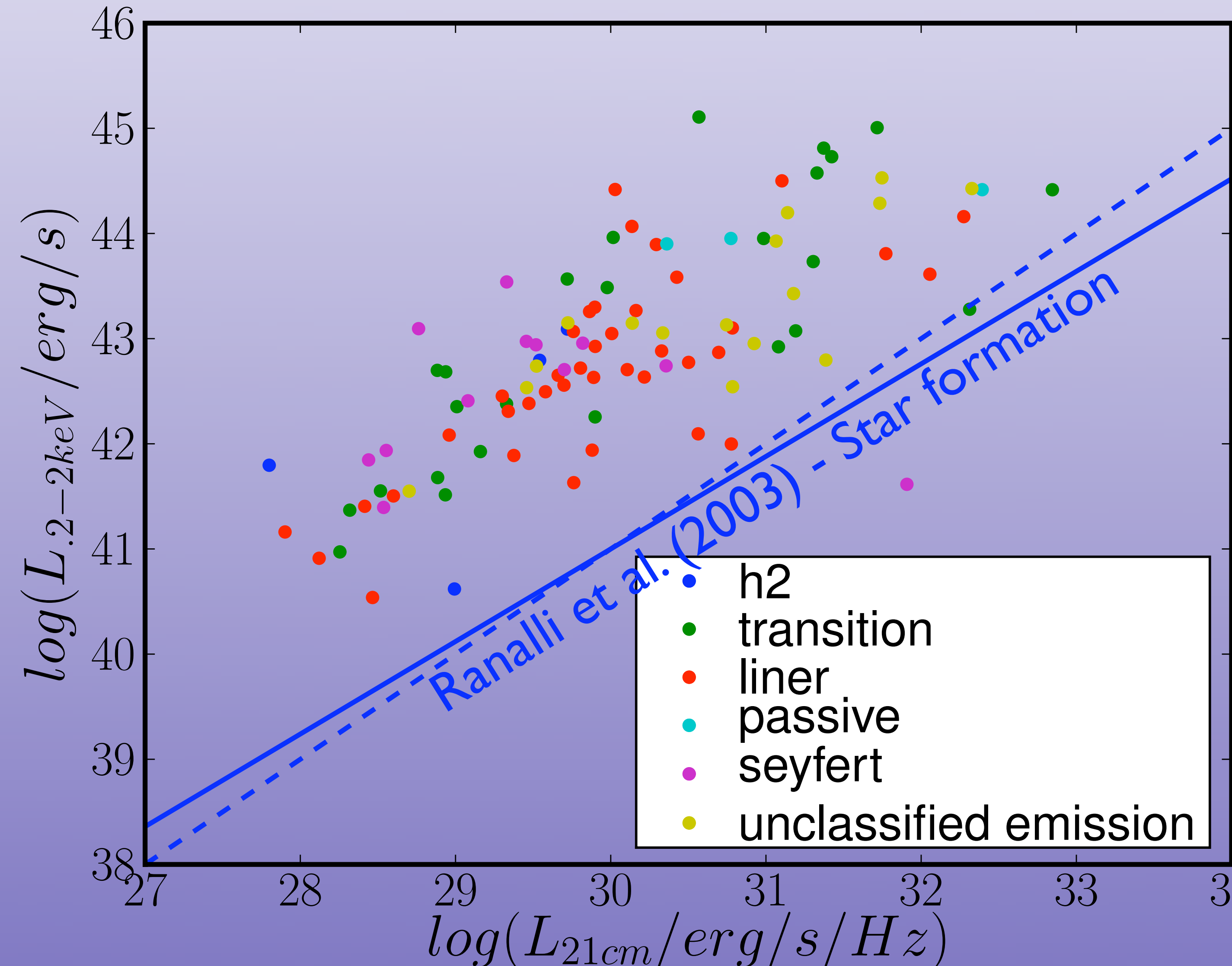
Break it up by optical spectroscopic classes (using the Kewley et al. classification that was explained in the Plenary session two days ago). Now some distinct patterns emerge. We can now definitely use this to extract high-likelihood matches for LINER, Seyfert and Transition galaxies, as well as unclassified emission ("ambigious"). And *NO* HII galaxies. This provides a very homogeneous dataset, with the same selection and data for all classes.




We take the matches above 75% likelihood and compare the RASS fluxes with the Halpha narrow-line fluxes. Data from Ho 2001 and Panessa 2006 are shown for comparison. The results are broadly consistent, however our X-ray fluxes are higher and the data suggests a different slope than the previous studies, and a trend in slope from S->T->L. We believe that this is due to our sample's broader parent distribution and uniformity.

# Non (or weak) correlations

- Star formation
- X-ray vs. 21cm radio correlations seen previously in high SFR galaxies
- Correlation from Ranalli, Comastri & Setti (2003)

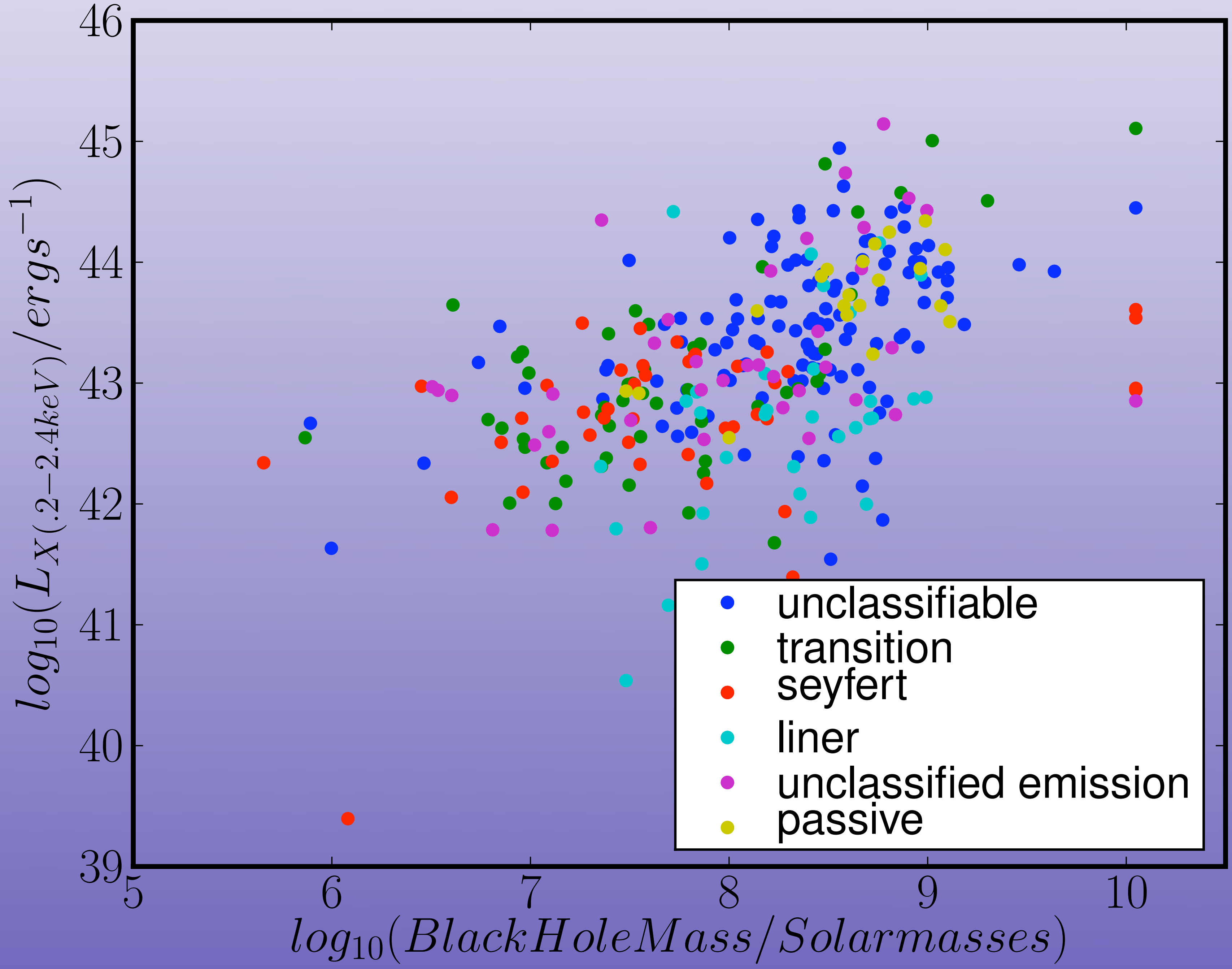



To rule out contamination from star formation, we compare our sources that have 21cm radio emission from FIRST with Ranalli 2003. Essentially all of our sources lie well above their relationship, giving us confidence that the X-ray emission in our sample is not due to star formation activity.

-Note: H IIs are included to test whether the method is being reasonable.

# Non (or weak) correlations

## $L_X$ vs. Black Hole Mass (from $\sigma_*$)




BH Mass from M-sigma via. Tremaine 2002. There is appears to be no correlation, consistent with previous studies. The trends you do see (in the colors) reflect the trends in BH mass with spectral class.

# Conclusions

- A very uniform dataset, including all different classes of LLAGN.
- Transition galaxies can host powerful AGN.
- HII galaxies are undetected in soft X-rays
- Soft X-ray to Hα emission consistent with 2-10keV studies.
- No clear signs of Soft X-ray to radio correlation.
- No clear signs of Soft X-ray to black hole mass correlation.

Mention White et al. (X-ray stacking).
"Remember Quasar Season?": there are some broad-line objects in this sample that shouldn't be: they are not identified by the SDSS QSO automated pipeline, the by-eye "pipeline," the Garching spectrometry code, etc. They are spectrally identified as galaxies, with no obvious way to tell that they have broad Ha (sometimes very strong!).

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- Mis-classified (spectroscopically) Sy1.8/1.9 show up in this sample.

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# And now a word from my archnemesis

And now a word from my archnemesis

Kevin Schawinski...

(Just don't tell him that!)

# Astroph: 0901.1663

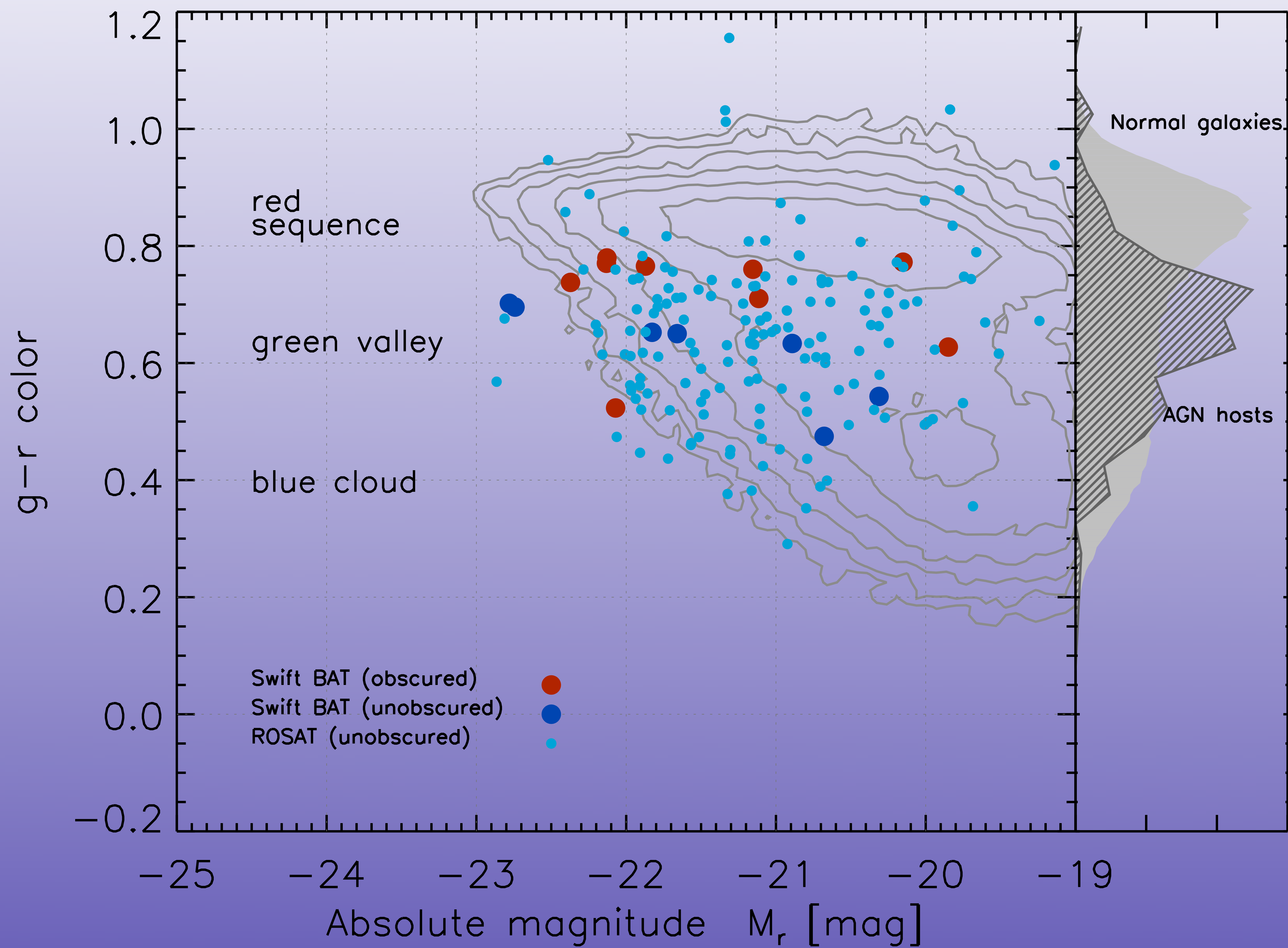
DO MODERATE-LUMINOSITY AGN SUPPRESS STAR FORMATION?

Kevin Schawinski,[1,2] Shanil Virani,[1,2] Brooke Simmons,[1,2] C. Megan Urry,[1,2] Ezequiel Treister,[3,4] Sugata Kaviraj[5,6] and Bronika Kushkuley[1,2]

*Accepted for publication in the Astrophysical Journal Letters 12/24/08*

Uses the Swift BAT catalog of hard X-ray sources (obscuration doesn't matter!)

# A measure of star formation

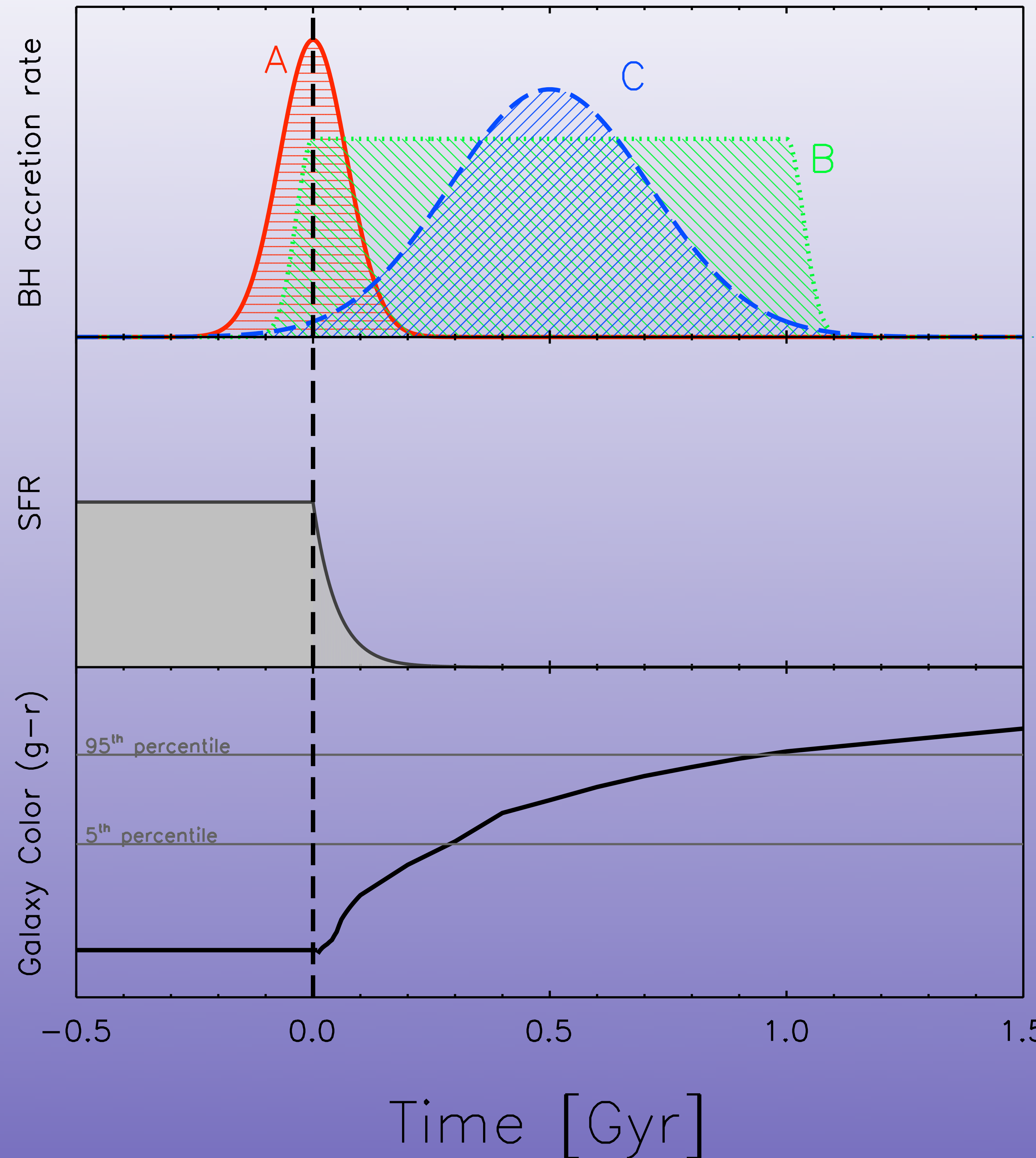



As you may have noticed, astronomers love plotting variables against each other. This is a color magnitude diagram: more blue toward the bottom, red toward the top. Bright on the left, dim on the right.

A. Short-lived, bright "quasar" phase

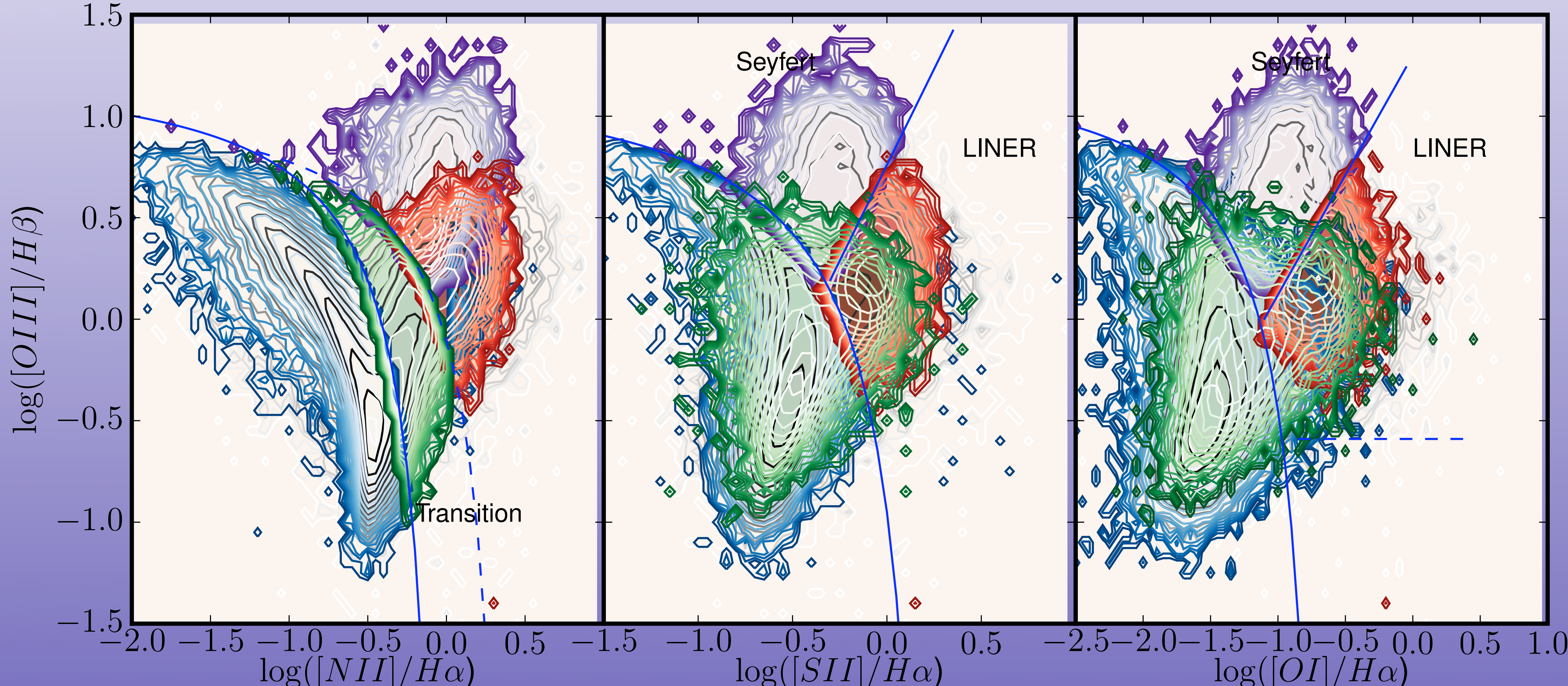
B. Quick turn-on, long life, moderate luminosity

C. Slow turn on, late peak in luminosity




g−r percentile lines are of the X-ray selected AGN from the previous plot.
Which of these three "models" is most likely, given the data that you've seen?

# Moving forward: DR7




This is a new emission-line classification done by me for DR7. It shows I'm making progress.

How do AGN shut down star formation?

How do we find out?

How do we prove it?

My thesis? Trying to get closer to the answer to these questions.